

## THE MANAGEMENT OF CHEST WOUNDS

### Collective Review

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THE chest, forming such a large and exposed part of the body and containing such vital structures as the heart and lungs, is particularly vulnerable to trauma. While in civil practice grave thoracic injuries are relatively infrequent, in military practice chest wounds assume serious and significant importance. This is clearly emphasized by numerous statistical reports. Reviewing war wounds in 11,000,000 men of English, French, American, and German nationalities, Hoche (210) found that the chest was involved in 6 per cent and was preceded in frequency of involvement only by the limbs and the head, face, and neck. The total mortality in this series was 8 per cent, whereas that in the chest wounds was 56 per cent and second only to that of abdominal wounds (68 per cent). In reviewing the cause of death among 12,350 killed, Hoche also found that the distribution of the wounds according to body region was: head, 47 per cent; thorax, 20 per cent; abdomen and pelvis, 11.8 per cent; and limbs, 9.9 per cent. Soltau (404) found that during the last World War, chest wounds comprised about 3.5 per cent of all casualties admitted to the casualty clearing stations. In the American Army during the World War (1917-1918) there were 174,296 admissions resulting from battle injuries, poison gases excepted (282). Among this number, the thoracic region was involved in 4,595 cases (2.6 per cent), being preceded in frequency of involvement only by the limbs and the head and face. While the total mortality was 7.73 per cent, that of chest wounds was 24.05 per cent. In the recent Spanish Civil War, Trueta (433) found that of 9,850 patients treated in different hospitals in

Barcelona, 12.1 per cent had thoracic injuries, an incidence second only to that of injuries of the limbs. Sauerbruch (374) stated that of 300 soldiers dying on the battlefield, 37 per cent showed wounds of the chest. Similarly, among 469 dead on the battlefield, Loeffler (265) found chest injuries in 29 per cent. According to Crafoord (95), chest wounds cause from 30 to 40 per cent of all fatalities in war. The mortality of chest wounds inflicted during warfare varies according to different authors but the proportion of chest wounds to all others, even in past wars, seems to bear a remarkable uniformity. According to Ranson (351), 1 wound in every 12 is of the chest. In the Sino-Japanese War, he found that chest wounds constituted 9.7 per cent of the total admissions to a base hospital in Shanghai. Obviously considerable difficulties exist in the attempt to estimate the number of fatalities in the field due to chest wounds. A number of observers have given figures of well over one-third of the total killed (85, 95, 162, 228, 265, 351, 374, 384).

That definite progress has been made in the management of war wounds of the chest is revealed by the decreasing mortality statistics quoted by Ranson (351) for various wars since the Crimean. In this conflict the English lost 79.2 per cent; the Americans in the War Between the States, 62.6 per cent; the Germans in the Franco-Prussian war, 56.7 per cent; the British in the last world war, 27.5 per cent; and the Chinese in the current Sino-Japanese war, 14.8 per cent. It is perhaps too early to obtain estimates of this nature in the present great conflict. In the last World War the mortality statistics for patients admitted with chest wounds varied considerably and depended to a great extent upon the source of material. Thus, the mortality was very high

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in the advanced dressing stations and ambulances and decreased progressively with regression to the base hospitals. This is readily comprehensible and is demonstrated by the statistics of a number of authors. Duval (115-119) gave a mortality of about 30 per cent at the dressing stations; 25 per cent in the ambulances; and 15 per cent in army hospitals. Somewhat similar figures have been reported by others (113, 162, 172, 328, 329). Duval (115) found a general mortality of 20 per cent in a collected series of 3,453 cases of chest wounds sustained during the last war and reported by thirty-seven authors. As statistical figures upon chest wounds during the last World War may be found in the reports of numerous others (134, 152, 160, 201, 263, 264, 290, 367), no useful purpose is gained by quoting these further. The statistics presented on the frequency and mortality of chest wounds in warfare clearly emphasize the significance of such injuries and justify their serious and timely consideration.

Although the fundamental principles involved in the management of chest wounds occurring in civil life may be applicable to those occurring in military practice, considerable differences exist in these two types of injuries and in the problems respectively entailed. In general, chest wounds in civil life are less extensive and less severe than those occurring in warfare. Such wounds in civil life are most commonly produced by knives, ice-picks, and pistol bullets, whereas in warfare the more extensive damaging effects of shell fragments, shrapnel, and explosive blasts are usually observed. In an analysis of 1,187 patients with chest wounds admitted to the Grady Hospital in Atlanta, Boland (50, 51) found that 1,009 (85 per cent) of the wounds were penetrating and 162 (15 per cent) were non-penetrating. Of the former, 79 per cent were stab wounds and 21 per cent were gunshot wounds. Empyema and other serious infections occurred in less than 20 per cent of the cases. Of his series of 553 cases Elkin (130) observed that 354 (62.2 per cent) were stab wounds produced by the "switch blade" knife, 93 (16.8 per cent) were produced by the ice pick, 84 (15.2 per cent) were the result of pistol bullets, 18 (3.2 per cent) were due to the shotgun, and the remainder (4) were caused by nails, splinters, and automobile accidents. Infection occurred in only 1.4 per cent of the cases. During the five-year period ending in 1936, 2,091 patients with chest wounds were admitted to the Charity Hospital in New Orleans and of this number only 13.8 per cent had definite evidence of hemothorax (80). The majority of these cases were due to stab and gunshot wounds and only 2 patients had crushing

injuries. It was estimated that infection occurred in 1.4 per cent of the chest wounds admitted during this period. The relative infrequency of severe crushing injuries of the chest is further demonstrated by the fact that among 16,000 cases admitted to the accident room in this institution only 75 were injuries such as follow automobile accidents (352). These statistics demonstrate clearly that in civil life chest wounds are most commonly of the stab or closed penetrating type in which extensive tissue injury, disturbance in cardiorespiratory physiology, and the development of infection are minimal. For these reasons chest wounds occurring in civil life are more readily adaptable to conservative management. On the other hand, chest wounds occurring in warfare are most commonly produced by such agents which cause extensive tissue damage and result in open pneumothorax. Consequent hemorrhage, shock, and marked disturbances in cardiorespiratory physiology are more frequent. Foreign-body retention and contamination with bits of clothing, dirt, and debris increase the incidence of infection. For these reasons operative intervention is more frequently necessary and usually indicated earlier. Moreover, in the present conflict, in which the keynote of warfare is perfection of mechanization and mobility, the problem of administering first aid and the collection and the transportation of the wounded increase the difficulty of adequate management (89, 358, 433). Of interest in this connection is the increasing significance that air transportation of the wounded is assuming (10, 245).

It is beyond the scope of this presentation to complete an extensive review of the literature on this subject. While this review is concerned primarily with the management of chest wounds in general, partial emphasis will be applied to those occurring in warfare and especially in the present conflict. For this reason reference will be made particularly to relatively recent articles and the inclusion of older literature will depend only upon pertinent application. Obviously an adequate conception of thoracic anatomy and cardiorespiratory physiology is essential for the proper management of chest wounds. It is considered inopportune and inexpedient to attempt here a detailed consideration of this phase of the subject. It must be realized, however, that a thorough appreciation of these facts is necessary for a comprehension of the derangements produced by injuries and for the institution of appropriate therapy (389).

The principles underlying the treatment of thoracic injury have been succinctly stated by Berry (32-34) and consist in: (1) the treatment of

surgical shock and hemorrhage, if present, by the institution of appropriate measures, and (2) the restoration of the thoracic viscera and of the cardiorespiratory physiology to their normal status as soon as possible. Shock is usually the first and most important consideration in severe chest injuries. According to Butler (77), "A certain degree of shock is desirable" because it is an "attempt on the part of the organism to control hemorrhage . . ." While it is true that under such circumstances shock may be considered a compensatory mechanism, it is highly undesirable for the patient to remain in this condition long. The consequences of prolonged shock are too well known to require further discussion (44, 184, 294). Suffice it to say that one of the first considerations in the management of severe chest injuries is the treatment of shock. As emphasized by Sellors (387, 388) and Blades (43), shock in severe chest wounds differs somewhat in manifestations and in management from that observed in wounds of other parts of the body. In the former the mental condition is unusually active and anxious and because of possible mechanical interference with vital capacity due to hemorrhage or an open pneumothorax, dyspnea and even cyanosis may be prominent manifestations. Painful respiratory movements and coughing may further increase these difficulties and exhaust the patient. For these reasons the first-aid measures must include not only the treatment of primary shock, but also the correction of the factors causing respiratory difficulty. Morphine for the relief of pain, anxiety, and possible restlessness should be administered immediately and preferably intravenously for more prompt results. The application of heat is essential. The administration of oxygen is a valuable adjunct and its effectiveness in the treatment of shock and the relief of dyspnea and cyanosis has been emphasized by a number of observers (355, 356, 387, 388). Placing the patient in a restful posture and inducing comfort are extremely important both as regards combating shock and decreasing respiratory embarrassment. In this respect the posture used in those patients differs from that used in shock from other injuries. Most observers agree that the propped up or sitting position is better than the conventional supine or Trendelenburg position because breathing is easier and the patient is more comfortable (43, 124, 153, 188, 246, 346, 353, 397). Because an associated rib fracture or other chest-wall injury produces excruciating pain, which contributes further to shock, it is desirable to immobilize the chest wall as well as possible. This may be accomplished by adhesive strapping or by a multiple

tape binder. In this connection Blades (43) emphasizes the importance of the method used in immobilizing the chest wall and states that the method usually described consisting of placing the adhesive strip over the fractured rib and including slightly more than half the chest is inadequate. He considers partial immobilization of the entire thorax, regardless of the level of the fracture with a single strip of adhesive which encircles the lower costal margin as a much more effective procedure. The administration of fluids to restore the circulating blood volume is also important. Such fluids should preferably consist of blood or plasma. Obviously, in these patients they should be administered judiciously. In addition to these first-aid measures to combat shock, hemostasis especially of the parietes should be effected and an open pneumothorax immediately closed. These will be discussed further in the consideration of such complications. While other therapeutic measures may be necessary in the management of the various manifestations of the different types of chest wounds, these procedures are designed primarily to combat shock and to prepare the patient for transportation or for further therapy. This is particularly applicable to chest wounds occurring at the battlefield where the exigencies and adversities of circumstance do not permit the time-consuming preparation necessary for the complete management of such cases. In timely articles Roberts (355) and Talbot (417) have directed attention to these facts and have summarized these first-aid measures as follows: (1) adequate treatment of shock; (2) administration of morphine to relieve pain; (3) immobilization of the chest wall by strapping if fracture is present; (4) placing the patient in the position of greatest comfort for transportation, and this is probably the propped-up posture; (5) immediate closure of open pneumothorax and relief of intrapleural positive pressure; (6) control of progressive bleeding from the chest wall; and (7) administration of antitetanic serum.

Before discussing further the management of chest wounds it may be desirable to consider briefly the prophylaxis of these injuries. The relative frequency and the undeniable gravity of chest wounds especially in warfare have been clearly demonstrated. Moreover, as Walker (446, 447) has justifiably emphasized, a relatively large number of soldiers in the front line are injured or killed by small fragments of grenade or shell piercing the front of the chest, "splinters that ripped open the heart, or the roots of the great blood vessels, and caused almost instantaneous death." He directs attention to the occasional

miraculous escape from fatal injury because of deflection of these splinters by the presence of such breast-pocket articles as a cigarette case or a New Testament. During the last war an analysis of the wounded reaching the casualty clearing station revealed that slightly over 60 per cent were caused by projectiles other than bullets. Of interest in this connection are the figures given by the Medical Department of the United States Army in the last War (282). In a series of 2,387 chest injuries in which the military agent was specified, 35.2 per cent were due to rifle balls and 65.7 per cent were due to shell and shrapnel. Walker (446) divides the velocity of these various agents into three categories: (1) low velocity (up to 600 ft. per second); (2) medium (up to 1,200 ft. per second); and (3) high (up to 2,800 ft. per second). By the use of appropriate armor it is possible to stop missiles of low and medium velocity. Accordingly, protection would be afforded against shrapnel, hand grenades, revolvers, automatic pistols, and some splinters. For this purpose Walker suggests the use of a jerkin made of laminated steel segments which would permit unrestricted motion and weigh only fourteen pounds. Other lighter material such as compressed fiber or canvas and bakelite may be used. Walker (446, 447) mentions that he has been informed that German shock troops are protected. Obviously such a prophylactic measure warrants serious consideration.

In discussing the management of the different forms of chest injuries and their varied manifestations and complications, a number of classifications have been proposed (8, 35, 43, 47, 48, 66, 109, 124, 126, 178, 190, 200, 255, 290, 355, 367, 418). Generally these are unsatisfactory or inadequate because not infrequently such wounds are complicated by a variety of lesions producing a number of different manifestations. However, for purposes of convenience and expediency the classification given on this page is used:

Of the non-penetrating chest wounds, the simplest forms are those that involve the thoracic wall only and produce no visceral lesions. These are usually the result of some blunt force striking the chest. Because of the greater elasticity of the thoracic cage in children than in older individuals such injuries in the former are less likely to be associated with rib fractures. Those lesions involving only the soft parts of the chest wall, such as contusions, abrasions, and hematoma, are of little or no consequence. Unless some complication such as infection of a hematoma occurs, no special therapy is necessary. On the other hand, non-penetrating chest injuries associated with rib

## I. Non-penetrating

### A. Parietes

1. Soft-parts injury
2. Skeletal injury

### B. Viscera

1. Pleuropulmonary lesion
2. Cardiac and mediastinal injury
3. Diaphragmatic injury
4. Commotio thoracis
5. Traumatic asphyxia
6. Blast injury

## II. Penetrating

### A. Parietes

1. Laceration
2. Compound fracture

### B. Viscera

1. Pleuropulmonary lesion
2. Cardiac lesion
3. Lesion of mediastinal structures
4. Diaphragmatic injury

## III. Thoracico-abdominal injury

fracture may have serious consequences. The ends of the fragments may penetrate the pleura and lung or produce wounds of the intercostal and internal mammary vessels which result in tension pneumothorax, emphysema, or hemothorax. These complications are of much greater significance than the chest-wall lesion. Rib fracture is not as likely to be associated with these complications in civil practice as in warfare. Because of the relatively protected position of the upper ribs and the greater mobility of the lower ribs, the fracture usually involves the fifth to the ninth ribs. These fractures may not be demonstrable by roentgenography (372) and the diagnosis must depend upon the history, the manifestations of sharp localized pain on respiration, and exquisite tenderness in the injured area. In a series of 124 cases of blunt injuries of the chest, Westermark (459) found that rib fracture was demonstrable by roentgenography in about 45 per cent. Treatment in such simple fractures is seldom operative. Immobilization of the chest wall by adhesive strapping or swathing is usually sufficient. The strapping should be done in overlapping layers from below upward and fixed during full expiration. While some surgeons advocate the application of the adhesive wall beyond the midline anteriorly and posteriorly, others (43) prefer placing the strapping completely around the lower chest wall and believe this method permits greater immobilization. The manipulative method recommended by Teal (421) for reducing rib fractures appears unnecessarily complicated and per-

haps exhausting. In 1933, Latteri (243) suggested alcoholization of the intercostal nerves as a simple and effective method of treating rib fractures. This procedure is based upon the principle of producing immobilization of the region innervated by the alcoholized nerves and, according to Latteri (243), placing the lung at rest. Recently the method has been recommended especially in war wounds by other Italian surgeons (79, 304).<sup>1</sup>

In the more extensive chest-wall injuries several ribs may be fractured at two or more points which results in the so-called "stove-in chest." Such injuries are usually due to direct violence causing a sudden decrease in the anteroposterior diameter of the chest and in civil life are most commonly caused by automobile accidents (43, 352). There is usually an anterior and posterior fracture, the latter occurring at the angle of the ribs. As a result of the fact that the rib fragments between these two fractures are deprived of their support this segment of the chest wall becomes depressed during inspiration and bulges out during expiration. This produces paradoxical respiration which is similar in effect to an open pneumothorax. Immediate careful immobilization of the chest wall is necessary because if this condition is allowed to continue the resultant cardiorespiratory embarrassment may be fatal. It should be realized, of course, that such an injury is not infrequently associated with varying degrees of intrathoracic damage resulting in pneumothorax, hemothorax, and emphysema. After immobilization of the chest wall a careful examination is necessary to determine their presence and extent and appropriate therapy should be instituted.

Fracture of the sternum is not infrequently associated with visceral damage because of the force required to produce this injury. Its occurrence is relatively rare although its presence causes little difficulty in diagnosis because of the deformity due usually to the protuberant lower fragment overriding the upper. Various methods of reduction have been suggested. This may be attained by hyperextension of the neck and chest, which may be accomplished by having the patient lie on a sandbag placed between the shoulder blades. Pressure is then applied to the upper end of the lower fragment. Other simple procedures consist of applying traction to a corkscrew driven into the fragment or hooks attached to the bone margins (352). In some cases open reduction and

fixation will be necessary (126). Of particular interest in sternal injuries is the subsequent development of traumatic chōnēchondrosternon (312). Cases of this nature have been reported by a number of authors (2, 30, 268, 467). A comprehensive review of this subject has been presented by Ochsner and DeBakey (312).

Non-penetrating chest wounds causing visceral lesions are usually associated with some parietal involvement such as severe contusions or fracture of the ribs or sternum. These are usually due to severe compression or crushing injuries. However, in some instances damage to intrathoracic structures occurs in the absence of demonstrable evidence of chest-wall lesions. For this reason the extent of intrathoracic damage cannot be gauged solely by the degree of chest-wall injury. Schwartz and Dreyfus (385) collected 29 cases of laceration of the lung without rib fracture. The possible seriousness of such injuries is demonstrated by the fact that there were 16 deaths in this series. Whereas in most instances these injuries are the result of direct violence caused by blows, falls, automobile accidents, or falling masonry, Berry (34) has directed attention to a "fairly large and interesting group of accidents," which "occur quite spontaneously during fits of crying in infants, paroxysms of coughing or sneezing, sudden straining or wrenching movements with increased intrapulmonary pressure or occasionally without apparent cause." Of interest in this connection is the occasional occurrence of spontaneous pneumothorax and hemopneumothorax. Wilson (463, 464) has presented comprehensive studies of the conditions which may follow trivial or no injury. In warfare these injuries are most frequently caused by falling masonry or débris from shell fire and bomb explosions, and in the last World War they were caused by the caving in of dugouts or trenches, and by airplane accidents. The lesions produced by such injuries as well as those associated with penetrating rib fracture usually involve the pleuropulmonary, cardiac, vascular, and other mediastinal structures, and the diaphragm. Simple contusion of the pleura and lung may result in a pleurisy with or without pleural effusion. If a traumatic pleurisy alone exists, management is relatively simple and consists of keeping the patient at rest and administering symptomatic relief. Other pleuropulmonary lesions consist of rupture, tearing, or laceration by penetrating rib fragments, hemorrhagic consolidation of the lung, massive atelectasis, and rupture of the bronchi. It should be realized that "contrecoup" injury of the opposite lung may exist and the resultant pleuropulmonary lesion may be even

<sup>1</sup>Since this was submitted for publication, Harmon, Baker, and Kornegay (*J. Am. M. Ass.*, 1942, 118:30) have reported their experience in treating uncomplicated fractures of the ribs by infiltration of procaine hydrochloride and eucupine dihydrochloride solutions directly into the site of the fracture. The good results obtained in 32 cases of minor rib fractures and 5 cases of major thoracic injuries by this method of therapy support the advantages claimed by the authors.

more extensive than in the side of contact (115). In this connection it should be realized that, while not frequent, contralateral disturbances such as pleurisy and pleural effusion, bronchitis, pneumonia, and massive collapse may occur in chest injuries (100). The vascular lesions consist of rupture or tearing of the intercostal, internal mammary, or azygos vessels and rarely the larger hilar vessels. Occasionally massive mediastinal hemorrhage is observed (471). Injuries of the aorta are almost invariably fatal. Similarly, wounds of the vena cava are very serious and usually associated with other severe and fatal injuries. Occasionally vena-caval thrombosis occurs as a result of blunt trauma to the chest. An exhaustive consideration of superior vena-caval thrombosis and its occurrence as a rare complication of chest injury has been presented by Ochsner and Dixon (316), who reviewed 120 cases collected from the literature and reported 2 cases, 1 of which was due to non-penetrating trauma and the other to a gunshot injury. Other non-penetrating injuries of the mediastinal structures and of the diaphragm will be considered together with those following penetrating trauma. Injury to the heart in non-penetrating wounds will be discussed later.

The importance of pleuropulmonary injury in the intact thorax is probably insufficiently realized. This fact has been emphasized by Fallon (142), who in a recent publication presents an excellent review of the subject. According to this author, Morgagni (296) recognized and described this type of injury in 1761. Of historical interest in this connection is Handley's (183) recent report in which is described a skeleton discovered in Snodland, Kent, with evidence of an extensive crushing chest injury probably occurring in the fourth century A.D. Exhaustive reviews of this subject were presented by Schwartz and Dreyfus (385) in 1907, and by Fischer (146) five years later. Various attempts have been made to explain the mechanism of injury (114, 170, 339, 401, 402), and some have investigated the problem experimentally (93, 220, 237, 428). No attempt will be made to discuss these in detail. Suffice it to say that in general they are based upon the principle of sudden compression and resultant rupture in the possible presence of other contributing factors. The pathological lesion in the lung varies usually with the degree of trauma. Hemorrhage is probably the most common lesion and may be subpleural in simple contusions or more central and extensive in severer injuries. In some cases it may be massive and involve an entire lobe (375) or even both lungs (115, 244, 363). Ruptures of varying extent and character com-

prise the grosser lesions. These ruptures may be subpleural or central with an intact visceral pleura, or complete penetrating ruptures. Rarely actual rupture of one of the larger bronchi may occur (33, 84, 222, 227, 235, 281, 300, 396). Massive pulmonary collapse may occur in the severer contusions and crushing injuries of the thorax although it has also been recognized in trivial injuries and as a complication of wounds in other areas (58, 474). In this connection Lockwood (263) has recently directed attention to the occasional occurrence of massive collapse in individuals "wounded by a close-up shell or bomb explosion." Moreover, the collapse occasionally involves the lung on the opposite side of the injury (58, 100, 426). Bradford (58) in a thorough consideration of this subject directed attention to the fact that homolateral massive collapse may occur in cases of slight hemothorax and that "the degree of collapse was quite out of proportion to the size of the hemothorax." For this reason, there may be some difficulty in the interpretation of the physical signs and in determining the presence of the collapse. Of interest in this connection is the occasional case in which multiple small areas of atelectasis occur following trauma (218). Bradford (58) also distinguishes between the type of massive collapse occurring in chest wounds and the form more commonly observed in civil practice following operations. No attempt will be made to discuss this complication further as the pathogenesis, clinical manifestation, and management have been adequately considered in numerous previous publications (92, 164, 278, 299, 306, 386, 424). Suffice it to say that in chest wounds it probably occurs more frequently than is generally realized and the possibility of its presence should be constantly kept in mind. As regards the mechanism of production in these cases Bradford (58) rejects the idea of bronchial spasm or bronchial obstruction and states that it "is more readily explained as a result of the immobility and retraction of the chest wall and diaphragm . . . The mechanism by which this condition of the chest wall is produced is obscure, but possibly it is of reflex nervous origin." (58) On the basis of the pleuropulmonary pathological lesion Cooke (91) gives the following clinical classification: (1) the pneumothorax type in which the lesion is limited to rupture of a small number of alveoli with no evidence of hemothorax or hemothorax; (2) the parenchymal rupture in which there is an intact pleura and hemorrhagic infiltration of the lung substance; and (3) the combined type in which the visceral pleura is also torn with consequent hemopneumothorax.

The clinical manifestations of these injuries vary with the type and extent of the intrathoracic lesions. In the severer forms shock almost invariably occurs immediately following the injury and is frequently of an alarming character. Cough and hemoptysis are also present and dyspnea may be intense. It may be slight or massive but in those patients who survive the shock it is usually of a degree not sufficient to cause marked displacement of the mediastinal structures unless associated with pneumothorax. The presence of air in the pleural cavity is probably one of the most frequent manifestations and if the visceral pleura is torn in such a way that air escapes from the lung with each inspiration tension pneumothorax results which produces increasing dyspnea. Emphysema may be subcutaneous or mediastinal and also varies with the extent and type of injury. The former is frequently associated with rib fracture and is of no consequence if there is only slight intrathoracic injury. On the other hand, mediastinal emphysema may develop in the absence of rib fracture and be of such extent as to produce intense pressure symptoms requiring immediate intervention. In these cases of emphysema with an intact chest wall the air is believed to reach the mediastinum after rupture of the intrapulmonary bronchioles by traversing the peribronchial spaces (385). Once in the mediastinum it ascends along fascial planes and appears in the neck above the sternum. Roentgenology is of distinct value in the diagnosis of these non-penetrating pleuropulmonary injuries. Westermarck (459) has recently directed attention to the diagnostic value of this procedure and states that in a series of 124 cases studied in this manner 86.7 per cent had roentgenographic lung changes associated with rib fracture and 65.6 per cent had such signs in the absence of fracture.

Other later pleuropulmonary complications of these injuries consist of infection with resultant gangrene, lung abscess, pneumonia, and empyema. A number of observers have described so-called contusion or traumatic pneumonia (114, 325, 330, 347, 371, 410, 441). The relationship of trauma to the development of such chronic lung disease as tuberculosis is an important medico-legal problem (45). While it is conceivable that such lung injuries may result in diminished resistance to tubercle bacilli Sergeant (390) observed only 9 cases of tuberculosis in a series of 1,400 lung injuries occurring in warfare. Similarly in an extensive war experience Petit de La Villéon (337) records not a single case.

It is obvious from this discussion of these pleuropulmonary lesions that the immediate manage-

ment of such conditions must be concerned with first combating shock and second the correction of disturbances in cardiorespiratory physiology resulting from the development of such complications as pneumothorax, hemopneumothorax, hemothorax, and emphysema. Reference has been made to the treatment of shock and further therapeutic considerations will be limited to a discussion of the complicating factors.

As previously stated, pneumothorax is a frequent complication of chest wounds and may occur in any injury in which the pleura is torn. Accordingly, it occurs most commonly in association with rib fracture or in the presence of an intact chest wall as a result of lung parenchymal tears involving the visceral pleura. It may be unilateral or bilateral, although fortunately the former is far more common. Rarely traumatic pneumothorax may be complicated by infection. Head (195) reported 3 cases of spontaneous pyopneumothorax following non-penetrating injury of the chest and stated that this was probably the result of rupture of a focus of infection in the lung. In those cases in which the laceration or rupture of the lung exerts a valvelike action permitting only the ingress of air into the pleural cavity, tension pneumothorax results. In such cases the intrapleural pressure rapidly rises to an extraordinarily high level which results in increasing cyanosis and alarming dyspnea. This condition requires immediate treatment which consists of inserting a needle into the chest and aspirating the air from the pleural cavity. This procedure should not be delayed until a pneumothorax apparatus is available for measuring the intrapleural pressure (43). A sufficient amount of air should be withdrawn to permit comfortable respiratory effort or, if an apparatus is available for measuring intrapleural pressure, until this pressure is zero. Not infrequently the air will continue to accumulate so rapidly that it is necessary to insert a small catheter through an intercostal space and connect its lower end to a water-sealed system. In this manner the air in the pleural cavity is permitted to escape and the intrapleural pressure can be maintained at atmospheric level. When air no longer escapes, which usually occurs within several days, the tube is removed. The relief afforded by this procedure is quite dramatic. In lesser degrees of tension pneumothorax repeated aspiration is usually sufficient. Valvular trocars which permit the egress of air but prevent its ingress have been devised for the treatment of this complication (286). Unless complicated by other intrathoracic lesions, tension pneumothorax rarely requires operative intervention.

Emphysema is another complicating condition of chest wounds and may be subcutaneous or mediastinal, localized or generalized. The subcutaneous type is usually associated with rib fracture or lung tears at the site of pleural adhesions. This form, which is a striking manifestation when generalized, produces no serious consequences unless associated with mediastinal emphysema or more dangerous underlying lesions. Both subcutaneous and mediastinal emphysema may be combined with pneumothorax and in such cases therapy should be directed toward correction of the latter. Mediastinal emphysema may be sufficiently severe to produce serious compression of the structures in this area which results in such alarming manifestations as dysphagia, increasing dyspnea and cyanosis, marked dilatation of the veins in the upper part of the chest and neck, extrapericardial pneumatic tamponade, circulatory failure, and death. First appearing in the jugulum and the base of the neck the crepitant area rapidly extends in the subcutaneous tissues up the neck and down the chest and upper extremities, becoming generalized and occasionally producing a striking bloated appearance. Various forms of therapy have been suggested in this more serious form of mediastinal emphysema. Transverse incisions in the jugulum and base of the neck and the use of cup or suction drainage have been described as well as the production of artificial pneumothorax (90, 112, 161, 345, 408). As emphasized by Stenbuck (408), it would seem more rational to attack the problem at its source. Accordingly, in those cases in which there is a tear or laceration of the pleura aspiration of the pleural cavity or water-sealed drainage should be done. In those cases in which injury to a bronchus is suspected operative intervention with closure of the defect may be considered (43).

Hemothorax is probably one of the most common complications of chest wounds and varies in extent with the severity of the injury (57). In slight contusions the degree of hemorrhage is minimal whereas in the more severe traumas as in crushing injuries it may be massive. The hemorrhage may arise from a number of sources, such as the intercostal, internal mammary, and azygos vessels, as well as the larger intrathoracic vessels, but most commonly it arises from the lung parenchyma (3, 56, 57). Hemorrhage resulting from injury of one of the larger mediastinal or hilar vessels is rapid, massive, and usually fatal. On the other hand, bleeding from lung laceration occurs more slowly and gradually lessens as the lung becomes compressed. This is less likely to occur and bleeding will continue

longer in hemorrhage from an intercostal or internal mammary vessel because a greater intrapleural pressure is necessary to compress these structures. Head (196) has directed attention to the two factors, decreased blood volume and increased intrapleural pressure, which supplement each other and result in disturbances of the cardiorespiratory physiology following hemorrhage into the pleural cavity. Accordingly, hemorrhage produces a progressive decrease in the blood volume, in the cardiac output, and in the blood pressure, and causes peripheral circulatory failure with eventual death from oxygen lack. The increased intrapleural pressure produces: "(1) a progressive collapse of the lungs and decrease in vital capacity; (2) an increased resistance in the pulmonary circulation; (3) pressure upon the heart and great veins; (4) interference with the return of blood to the heart; (5) a rise in venous pressure; (6) a decrease in cardiac output; (7) a marked exaggeration of the respiratory variation in blood pressure; (8) eventual death from a practically simultaneous respiratory and circulatory failure." (196) On this basis Head (196) concludes that since "the two conditions supplement each other, the patient's symptoms, both respiratory and circulatory, may be relieved by either increasing the blood volume or decreasing the intrapleural pressure."

An interesting and striking feature of hemothorax is the frequent failure of blood in the pleural cavity to clot, even after it has been aspirated. Various attempts have been made to explain this phenomenon. According to some, a certain degree of clotting occurs in all cases and this is influenced by the rapidity of the bleeding (136, 200). In those cases in which the bleeding is slow and the volume of blood small, clotting is less likely to occur because this interval permits certain influences to modify the blood, i.e., the precipitation of fibrin into layers on the pleural surfaces and the defibrination of the blood by the churning movements of respiration. In the more rapid massive hemorrhage the time interval is insufficient to permit the operation of these factors and clotting is more likely to occur. According to Bradford (56) it has been shown that "the bloody fluid in haemothorax contains no fibrinogen, and hence, that although it resembles blood to the eye, clotting has really taken place, and that it is in reality defibrinated blood." In experimental hemothorax Sandison and Elkin (368) found that clotting occurred in some of the animals while it was absent in others and that it was more likely to be present in hemothorax. In commenting on this Van Allen



(442) emphasized the "powerful anticoagulant property" of the pleura and stated that "blood in the pleural space of patients with traumatic hemothorax may or may not be coagulated, and the explanation is probably that the hemorrhage was rapid in the cases with coagulation and slow in those cases without coagulation."

Apparently considerable controversy still exists regarding the management of traumatic hemothorax. Opinions vary from ultraconservatism to radical exploration. Between these two extremes there is the opinion of those who advocate aspiration followed by air replacement. Much of this diversity of opinion is probably due to comparisons of results of the different forms of therapy without adequate appreciation of certain influential factors. Thus in comparing civil injuries with war wounds, the factor of therapeutic application must be considered because in the latter instance the exigencies and adversities of circumstances differ. Moreover, the factors of infection and other complications play more prominent roles in the latter case. It is obvious after consideration of the various factors concerned that the management of traumatic hemothorax cannot be reduced to a simple formula but must be governed by the presence or absence of certain factors in the individual case. In a recent discussion of this subject Chandler (82) classifies the types of hemothorax into three groups with treatment modified accordingly: (1) simple and non-infected, (2) infected, and (3) complicated by many other factors. In simple limited hemothorax most observers agree that conservative therapy is preferable. If the amount of hemorrhage is small, little or no therapy except for the relief of pain is required. Some believe that even diagnostic aspiration in such cases is undesirable. Even if the extent of hemorrhage is greater some authors contend that conservative therapy is the method of choice and aspiration should be done only to relieve increased pressure manifestations. This is based on the assumption that the source of bleeding in such cases is usually from a lacerated lung and consequently is more likely to be controlled by the tamponade effect of the blood. Warner (453), in 1926, advocated phrenicectomy for the purpose of putting the lung at rest and preventing further hemorrhage. During the last World War, Morelli (295) began "to apply to wounds of the lung the concepts of (his) teacher, Professor Forlanini, formulated for the treatment of phthisis, of lung abscess, of bronchiectasis, and of serious hemoptysis." This method of therapy consisted briefly of aspiration and air replacement of the hemothorax. He (295) contended: "(1) that the

wounded lung heals quicker and better if it is immobilized and compressed; (2) that if the immobilization be secured early the great advantage is obtained of preventing or checking hemorrhage; (3) that if a hemothorax already exists, being harmful for many reasons, it ought to be evacuated with the substitution of air; (4) that pneumothorax is the ideal means of compressing the lung." He states that in a series of 40 cases of closed hemothorax all were cured. This method was further supported by the observations of Bastianelli (17, 18), who reported 206 cases of closed chest wounds, 88 of which were treated by pneumothorax and 118 by thoracentesis and pneumothorax with a mortality of 3.4 per cent. Of the 7 deaths, 3 were due to empyema, 1 to pulmonary abscess, and 3 to septicemia. Shattuck and Welles (392), using manometric studies in these cases, showed that existing intrapleural pressures can be maintained by the "simultaneous replacement of fluid withdrawn by oxygen volume for volume." It would appear from the reports in the literature that even during the latter part of the World War and afterward with return of interest to chest injuries in civil life, the method was popular only in the Italian Service and did not gain wide adoption. Colonel Yates (469), who was in charge of the American Medical Unit detailed to the study and treatment of thoracic injuries during the last World War, was an advocate of immediate open operation in the treatment of all but limited degrees of hemothorax and was opposed to Morelli's method. In criticizing the latter method he writes: "Air is a serous membrane irritant and elimination of irritation is a basic principle in the prevention as well as the treatment of pleuritis. Positive intrapleural pressure, high enough to stop hemorrhage by pulmonary compression, compresses the homolateral lung, produces contralateral emphysema, and interferes with pulmonary circulation. Compressed lung means contracted lung which is often difficult or impossible of reinflation. If reinflation occurs, a universal adhesive pleuritis is certain. The exact conditions for minimizing the resistance to the flow of blood through the lung, as established by Cloetta, a reduction of mean pulmonary inflation, are met by diaphragmatic paralysis. Diaphragmatic paralysis lasting four or five days can be established by infiltrating the phrenic nerve trunk with 1 per cent cocaine. If this procedure be coupled with closure of the chest without residual pneumothorax, the best conditions for repair and defense have been provided for both lung and pleura." That Morelli's procedure did not gain wide popularity is shown by Foster's report, in

1939 (149). This investigator sent questionnaires to leading surgeons affiliated with general hospitals in most of the larger cities throughout the United States and Canada requesting information concerning the type of therapy in hemothorax. He obtained data from 52 cities, and among this number aspiration and air injection was considered the method of choice in only 2 cities. Thirteen of the surgeons mentioned operative interference "only for the control of progressive hemorrhage, usually from the internal mammary vessels or for the repair of chest wall defects, most frequently depressed rib fractures." The remainder, 71 per cent, favored the method of so-called "watchful waiting." While it would seem that the expectant mode of care is the most popular especially among those treating civil chest injuries, it has definite objections which have been enumerated by Foster as follows: (1) excessive reabsorption time and resulting long hospitalization; (2) fluid alone acts as a poor compressor of the lung tissue and the gradual hemorrhage may not be controlled until the pleural cavity contains 2 or more liters of blood; (3) hemothorax forms an ideal culture medium for bacterial growth and pathogenic organisms may readily flourish in this closed space; and (4) the danger, infrequent as it is, of the formation of a thickening pleura or deforming intrapleural adhesions from failure of complete absorption of the blood.

With the recent revival of interest in chest wounds due to the present conflict there has developed an increasing and more favorable consideration of the aspiration and air-replacement method of therapy. In fact, a review of recent articles on the subject, especially of British authors, leads one to the conclusion that it is the procedure of choice (8, 32, 33, 73, 82, 110, 124-127, 143, 149, 150, 200, 214, 233, 261, 276, 289, 326, 338, 346, 353, 355, 357, 358, 425, 429, 457). In a consideration of traumatic hemothorax at a recent meeting of the Royal Society, Edwards (125) emphasized the value of this method and listed its "obvious advantages: (1) it removed the blood before clotting occurred; (2) it removed an excellent culture medium for organisms; (3) when the hemorrhage was the result of damage to the vessels of the chest wall and was continuing it could be diagnosed early by radiological examination or physical signs and before the general signs of hemorrhage were present if gas replacement had been carried out early, as the increase in fluid within the pleura was obvious owing to the presence of the air there. Where air replacement had not been carried out bleeding might continue without alteration in the physical or radiological

signs, as the lung gradually collapsed beneath the fluid until general signs of internal hemorrhage appeared; (4) it prevented the late results of pleural fibrosis and chest contraction and the occasional occurrence of encysted collections in the pleura." To these may be added the fact that the average duration of hospitalization is reduced by more than 50 per cent (149).

Because of the accompanying shock and frequent loss of large amounts of blood into the pleural cavity transfusion of whole blood or plasma is usually indicated in the management of hemothorax following chest injuries. Autotransfusion has been recommended by a number of authors (68, 77, 137, 149, 150, 196, 248, 454, 466). However, the procedure has definite objections. Unfavorable reactions and even fatalities following its use have been recorded, especially if the period of stagnation is longer than twenty-four hours (225). In a consideration of this subject Kilduffe and DeBailey came to this conclusion, "Whereas in desperate cases or grave emergencies autotransfusion may be considered, its indications are definitely restricted. This is particularly true at present because of the ready availability and effectiveness of plasma and the rapidity, facility, and safety of this form of transfusion."

Although secondary infection of hemothorax is more likely to occur in penetrating chest wounds than in the non-penetrating types, its possible development must be constantly considered. Early diagnosis of infection is essential and one should not wait until the classical manifestations of infection have developed before instituting therapy. For this reason emphasis has been placed upon careful examination of the aspirated fluid (82, 127, 214, 261) and determining the presence of infection by gross appearance, odor, and smear and culture studies. Chandler (82) states that if the aspirated fluid "has any unpleasant odour, it must be assumed to be infected, no matter what the bacteriological report, and treated accordingly without delay." Hoyle (214) emphasizes the value of performing smear studies and states that if organisms are demonstrable "treatment should begin at once." After establishing the presence of infection prompt and appropriate therapy should be instituted. This consists of drainage either by repeated aspiration or by closed intercostal drainage with waterseal. Hoyle (214) believes that in the early stages repeated aspiration is preferable and says, "It is a mistake to insert a drainage tube until the infection has become localized." Edwards and Davies (127), however, recommend closed water-sealed intercostal drainage and irrigation with 1 to 3,300 azochloramide solution. The

use of chemotherapy in the management of such infections will be discussed later.

At present most observers agree that the indications for immediate open operation in the treatment of non-penetrating traumatic hemothorax are limited. Following the last World War, however, there was an increasing sentiment favoring immediate intervention. This is indicated by Yates' (469) statement: "If it be granted that thoracotomy has become a safe operation, then cumulative evidence indicates that immediate open operation is the sane treatment for all but the limited degrees of hemothorax, even if restricted to the removal of the liquid and coagula." In the presence of massive or progressive hemorrhage as might occur in laceration of an internal mammary or intercostal vessel, thoracotomy may be considered. In any event operation should not be done until shock has been overcome. Some consider the presence of large clots as an indication for operation (104, 134). More recently Edwards and Davies (127) have suggested thoracoscopic removal of such clots.

As previously stated, massive collapse may be associated with hemothorax and may be homolateral or contralateral. Once the condition is recognized, every attempt should be made to dislodge possible obstructing clots or plugs of mucus. This may be accomplished by rolling the patient on the uninvolved side and inducing him to cough (369). While in other conditions in which this complication may occur coughing may be an effective means of accomplishing this, in chest wounds this may be difficult or ineffective because of pain, exhaustion, and other disturbance produced by the injury. Postural drainage may be helpful but if these measures are not efficacious, intratracheal aspiration or bronchoscopy should be employed (358).

In addition to pleuropulmonary disturbances in non-perforating chest injuries there may be cardiac involvement. According to reports in the literature such heart injuries occur relatively rarely. In 1935, Bright and Beck (65) presented an extensive review of the literature on this subject and collected 75 cases. They expressed the opinion, however, that although this would indicate its rare occurrence, such a conclusion is not justified because the heart can "tolerate a great amount of trauma," and for this reason probably "the vast majority of non-penetrating wounds of the heart are not recognized clinically." The exceptional cases, that is, those with death from rupture or contusion of the myocardium are reported, whereas the others "in which death does not occur apparently do not receive the correct

diagnosis and are not placed in the literature."

In 1938 Warburg (449) presented an exhaustive monograph on the subject in which he collected from the literature 202 cases. In a subsequent publication (451) he had brought the total number of reported cases to 261. The condition of non-penetrating cardiac injury is now well established and its pathological and physiological characteristics have been experimentally investigated (25, 65, 229, 238, 239, 297, 381). In the cases analyzed by Bright and Beck (65) the various factors which produced non-penetrating cardiac injuries were classified into five groups: (1) a direct blow over the precordium with penetration of the heart by fragments of rib or sternal fractures; (2) contusion or compression of the heart between the sternum and the vertebrae; (3) indirect violence resulting from sudden compression of the legs and abdomen or "jackknifing" of the body; (4) laceration of the thoracic viscera consequent to falls from great heights; and (5) cardiac concussion which is not satisfactorily defined. The type of cardiac injury which may result from the various forms of trauma obviously depends upon the extent of the traumatic force and the presence or absence of underlying pathological lesions. In general they may be classified into (12, 13, 378, 449-451): (1) rupture of the heart; (2) valvular lesions; (3) pericarditis; (4) disorders of rhythm; (5) angina; and (6) minor cardiac contusions. In the cases analyzed by Bright and Beck (65) rupture of the heart was the most frequent lesion, occurring in 152 of 175 cases. Although injuries resulting in rupture of the heart usually follow trauma of severe violence, cases have been reported in which there was no evidence of external injury (42, 182). The rupture involves the various cardiac chambers with about equal frequency (65). It may occur immediately, because of bursting of the heart by compression or from a sudden rise of intracardiac pressure resulting from the application of direct (145, 332, 333) or indirect forces (224, 373), or it may be delayed for hours, weeks, or months until the area of softening caused by the contusion gives way (173, 213, 321, 348). While in the majority of cases death occurs immediately from cardiac tamponade or extensive involvement of other vital structures, in others the fatal termination occurs at a later date from cardiac insufficiency or aneurysm. Obviously therapeutic consideration in the majority of these cases is precluded by the time factor alone. Of interest, however, is the fact that in the 152 cases analyzed by Bright and Beck (65) there were 30 that presented "opportunities for treatment that were not utilized." This emphasizes the import-

ance of considering the possibility of cardiac injury in those patients who survive the initial trauma. Signs of sudden increased intrapericardial pressure and circulatory embarrassment are indicative of rupture and the need for prompt surgical intervention is urgent.

Valvular lesions of the heart following trauma have been described by several authors (12, 13, 65, 165, 331-333, 361, 378). In 1865, Peacock (332) reported a case of rupture of an aortic valve from strain. In the case described by Barber and Osborn (14) the patient was "blown-up and buried in the débris" at the battle front in the last World War. Fifteen years after the injury the "signs were indistinguishable from those of mitral stenosis of rheumatic origin." He died of pneumonia twenty-two years following the injury and "the stenosis was very obvious and there were features which confirmed beyond doubt the diagnosis of trauma." Traumatic pericarditis with pericardial hemorrhage or fibrinous exudation occurs relatively frequently following blunt chest injuries (13, 166, 350). In his analysis of 261 cases of non-penetrating heart injuries, Warburg (451) found this present in 60 and states that it probably occurred more frequently. The diagnosis depends upon the presence of a pericardial friction rub, the occasional occurrence of characteristic splashing sounds, and the aspiration of serosanguinous pericardial fluid. In the majority of cases the disturbances are transient and the prognosis is good. Occasionally the development of such complications as infection and constricting adhesions may require further appropriate therapy.

Disorders of rhythm following this type of cardiac injury consist of auricular fibrillation, auricular flutter, extrasystoles, and varying degrees of heart block. Warburg (451) found that auricular fibrillation occurred in one-fifth of his collected series. In 10 cases analyzed by this author 2 of the patients recovered completely, 6 continued to have signs of cardiac impairment, and 2 died. The medicolegal significance has been discussed by Hay and Jones (194). Cases of auricular flutter have been reported by Barber (12) and Schleiter (378) but it is apparently infrequent and of transient character. Extrasystoles are also infrequently reported (223). There were only 11 cases in Warburg's (451) collected series. More recently Barber (13) reported another case in which the irregularity persisted a year after the accident. Heart block may be indicative of a deep-seated lesion. Cases have been recorded by a number of observers (86, 436, 445, 451) and in the collected series of Warburg auriculoventricular block occurred in 10 cases and sino-auricular block in 1

case. In some the disturbance is temporary while in others it may persist for years (121). In 1929, Kohn (231) directed attention to the syndrome of traumatic angina pectoris. Since then a number of cases have been reported and Warburg's most recent review included 16 cases. In 1937, Bean (22) reported 3 cases of coronary thrombosis following trauma and the subject has more recently been discussed by Meessen (283). Characteristic electrocardiographic patterns have been described (6, 450, 468) and experimental investigations have confirmed these findings (229, 381). On the basis of his experimental and clinical studies Schlomka (381) concluded that vasospasm of the coronary arteries may be initiated by sharply localized blows to the precordium in an analogous manner to segmental arterial spasm occurring in peripheral injuries. According to the duration of the ischemia, the damage to the coronary vessels and the myocardium may be transient or permanent. Boas (46) who has recently reported a case discussed the medicolegal aspects of this subject.

Minor cardiac contusions following chest trauma have been described by a number of observers (12, 13, 223, 253, 378). Barber (12, 13) records the cases of 7 patients "in whom the heart appears to have been inefficient after a severe blow on the chest." In these cases there were no abnormal signs on examination and the electrocardiogram was normal; the only evidence of myocardial weakness was an inadequate response to effort. Smith and McKeown (400) have recently reported a case of cardiac contusion in which a pericardial friction rub developed twenty hours after the accident and disappeared twelve hours later. Serial electrocardiograms revealed patterns similar to those associated with pericarditis. Because these cardiac disturbances are transient and the patients recover completely the diagnosis is difficult to establish. That complete recovery frequently occurs following considerable trauma to the myocardium has been demonstrated by experimental studies (65, 229, 381). Nevertheless the symptoms and signs of cardiac disturbances developing in a previously healthy individual immediately after a chest injury indicate heart damage.

It is evident from this brief review that varying degrees of cardiac injuries may follow non-penetrating chest wounds. These injuries probably occur more frequently than is generally realized and unless this possibility is kept constantly in mind the diagnosis is likely to be overlooked. This is especially true in minor contusions. Moreover, the diagnosis is frequently difficult to establish and requires considerable caution from the

medicolegal aspect which further emphasizes the necessity of careful clinical observations and laboratory investigations. Except in the immediately fatal cases, once the diagnosis of cardiac contusion has been made the patient's course may follow several possibilities (65): "(1) the symptoms may disappear hours or days after the accident, and the patient may remain well; (2) the symptoms may persist for years, and they may be accentuated by exercise; (3) the heart may fail hours or days after the accident; (4) the contusion may soften, and rupture may take place." According to Bright and Beck (65), in the management of these cases therapeutic measures should be instituted toward combating myocardial failure and cardiac rupture. These consist essentially of "absolute rest and the use of morphine or other sedatives as necessary. The heart should be saved as much as possible. Any exertion should be avoided. Mild laxatives should be given, if necessary, to avoid straining at stool. Digitalis may be indicated for the tachycardiac or auricular fibrillation." In cases in which there is evidence of pericardial effusion aspiration is advised. The diagnosis of rupture demands immediate operative intervention.

Commotho thoracis is a distinct clinical entity which follows severe non-penetrating chest injury with clinical manifestations of serious intrathoracic damage but with no objective evidence of anatomical disturbances (7, 43). During the last World War the condition occurred in soldiers who were near exploding shells but who received no visible evidence of having been struck. In civil life it has followed explosions and "other accidents in which the individual is badly shaken up and but narrowly escapes serious injury" (7). Intense emotional strain has been considered a significant etiological factor. During the last World War, autopsies performed on these cases revealed no explanation of the fatal termination. Clinically the condition is characterized by unconsciousness; cold clammy skin; feeble, slow, and frequently irregular pulse; and slow shallow respiration. While in some cases complete recovery ensues, in others death occurs in spite of all therapy. In the management of these cases therapy is essentially supportive and consists of the application of those measures commonly used in the treatment of shock.

Traumatic asphyxia, which is referred to in Germany as "Druckstauung" and in France as "masque ecchymotic," is another type of non-penetrating chest injury which may follow sudden brief violent compression of either or both chest and abdomen. Thorough considerations of this

subject have been presented by Heuer (205) who collected 127 cases, in 1923, by Laird and Borman (240) who reviewed 16 additional cases, in 1930, and recently by Bonnin (53). The condition occurs most commonly following the application of a direct compressing force such as the crushing weight of heavy objects, but not infrequently it follows diving accidents or so-called "jackknife" injuries in which the individual is forcibly "doubled-up" so that the thighs and knees are brought in contact with the chest and upper abdomen. This unique condition is characterized by a deep violet blue or bluish black discoloration of the face, neck, and occasionally the upper part of the chest, the shoulders, and upper arms associated with swelling and edema of the tissues in this area, and particularly in the lids and lips. Careful examination of the cutaneous discoloration reveals numerous minute ecchymotic or petechial hemorrhagic spots which may also involve the buccal and pharyngeal mucosæ and the auditory meatus. Not infrequently the discoloration is absent in areas corresponding to points of pressure on the underlying skin from collar bands, suspenders, and creases of clothing. Gradual fading of the discoloration begins from the second to the fourth day after the onset and has usually disappeared completely within two weeks. No characteristic chromatic changes are observed with this fading process, a fact which had led to the belief that the discoloration is due not to extravasation of blood into the tissues but rather to extensive venous stasis. This belief is further supported by microscopic examination of the discolored skin and subcutaneous tissue. Subconjunctival hemorrhages are usually present and occasionally retrobulbar hemorrhages associated with exophthalmos have been observed. Unconsciousness, occurring in about a third of the cases, is usually of short duration. Ocular and visual disturbances have also been observed. In a thorough investigation of this manifestation Heuer (205) found that there were 16 cases reported in the literature including his own in which immediate subjective visual disturbances were present. While in about a third of these cases these manifestations were transient, in others there was permanent blindness and progressive optic atrophy. The explanation for loss or impairment of vision in some cases is the presence of retinal hemorrhage, while in others it is probably "degenerative changes in the retina, the result of vascular stasis with oedema." (205) Various theories have been proposed to explain the striking manifestations of this condition and these have been briefly summarized by Heuer (205), but apparently none

is entirely satisfactory. Hueter (215) originally proposed the mechanical theory and considered the discoloration due to vasomotor paralysis and back pressure in the dilated veins. Subsequently Perthes (336) directed attention to the absence of functioning valves in the veins of the discolored area. Accordingly, Perthes believed that this explained the limitation of the discoloration which he thought was due to extravasation of blood following rupture of the peripheral venous capillaries consequent to the sudden increased pressure and reversal of flow. This theory is discredited by the histological demonstration of absence of hemorrhage into the tissue (21). In his recent consideration of the etiology, Bonnin is inclined to the theory of a wave of back pressure in the veins and states that apparently back pressure dilates the vessels, and that the anoxemia, which continues for the length of time the thorax is compressed, contributes to the paresis of the vessel walls, which become overdistended and so lose their tone. He comes to the conclusion that "a slow squeeze produces cyanosis, a rapid squeeze is likely to produce petechiae, and the combined type of injury produces cyanosis together with petechiae."

Associated lesions such as fractures of ribs and other bones and occasionally intra-abdominal injuries have been observed. Necropsy studies have been made by a number of investigators and these have been summarized by Heuer (205). Cerebral congestion has been the most significant finding in the brain (52, 60-64, 359). Examination of the skin and subcutaneous tissue revealed overdistended capillaries but rarely any blood in the tissues outside of these vessels (21, 52, 60-64, 359, 465). Intrathoracic lesions consisted of hemothorax, subpleural and pericardial hemorrhages, laceration or rupture of the lung, congestion and hemorrhagic consolidation of the lung, and bronchopneumonia (52, 60-64, 202, 242, 287, 305, 318, 320, 359). Abdominal lesions include hemoperitoneum; laceration of the liver, spleen, kidney, and diaphragm; perforation of the duodenum and bladder; and hemorrhagic infiltration and congestion of the viscera (52, 60-64, 205, 242, 287). In the absence of these severe associated injuries traumatic asphyxia in itself is apparently not serious and requires no specific therapy. The majority of the patients recover completely. Among the 127 cases collected by Heuer (205), 27 patients (21.2 per cent) died immediately after the injury and 8 (6.3 per cent) of subsequent complications.

Another type of non-penetrating chest wound which is assuming increasing significance in the current European conflict is the so-called "blast

injury" to the lungs. This is a form of chest injury which occurs in individuals exposed to the detonation of a high explosive such as a bomb, which produces characteristic clinical manifestations and pathological lesions in the lungs. While during the last World War the condition was not specifically recognized, reference was made to the finding of dead soldiers in the field after explosions without serious external injury but not infrequently with blood-stained fluid in the mouth and nose (263, 266). Referring to 250 cases of chest wounds occurring during that war Thomson (426) states that there were "24 cases of non-penetrating wounds or cases in which penetration was doubtful," and in which "injury involved either the lungs or pleura as shown by haemoptysis, pleurisy or pulmonary collapse." In commenting upon these cases Zuckerman (472) states that, "the blood-stained fluid which is found in the mouth and nose in cases of this kind is due to traumatic haemorrhage in the lungs." Similar forms of chest injuries were observed in the recent Spanish War (179, 234, 395). Probably as a result of ruthless and indiscriminate bombing in the present great conflict this type of injury is apparently assuming serious proportions and receiving significant consideration (105, 123, 141, 174-176, 233, 234, 322, 355-358, 364, 365, 415, 461, 472, 473).<sup>1</sup> The most extensive inquiry into this subject has recently been reported by Zuckerman (472, 473).

In discussing the physics of blast Sutherland (415) and Zuckerman (472, 473) direct attention to the similarity between a blast wave and an excessively intense sound wave. Zuckerman (473) states that in the detonation of a bomb, "the solid explosive is converted into gases which are confined in the casing at a pressure that has been variously estimated as between 100 and 650 tons per sq. in. As a result of this pressure, the casing is blown to pieces, and the gases escape, and by their expansion produce a blast wave in the surrounding air. The blast wave is a single pulse of increased pressure followed by a phase of suction, and in general form is similar to a single pulse of a large amplitude sound wave." The movement of this wave is extremely rapid and its total duration very brief. The blast wave has two components: a pressure component and a suction component. Obviously the latter is considerably weaker than the former because the suction component can never be "greater than 15 pounds per sq. in., since this corresponds to a perfect vacuum." (473) Several factors influence the magnitudes of

<sup>1</sup>A recent comprehensive review of this subject was presented by King and Curtis (*Surg., Gynec. & Obst.*, 1942, 74:53).

these components of a blast wave. Obviously larger amounts of explosive increase the magnitude. Moreover the pressure is higher closer to the explosion and rapidly decreases with distance from the source. This may be demonstrated by the hydrostatic pressure produced by the explosion of a 70 lb. charge; at 14 ft. it is 110 lb.; at 18 ft. 60 lb.; at 30 ft. 15 lb.; and at 50 ft. 6 lb. In considering the effect of blast Zuckerman (473) states that all objects "in the immediate neighborhood of an explosion . . . first experience a violent increased pressure, which may tear them to pieces and blow them far from the scene of the explosion, or affect them directly without doing either of these things. Whether or not an object is shattered by, and blown in the direction of, the pressure wave, it may later be pulled towards the centre of the explosion by the backward movement of air associated with the weaker suction wave, because of the longer time for which this acts."

A number of clinical and experimental investigations on the physiological and pathological effects of explosion blasts have been performed. Toward the end of the last World War some experimental observations on the effects of blast were made by Marinesco (274), Mairet and Durante (272), and Hooker (212). These investigators found that the most striking lesions were hemorrhagic and occurred in the lungs, central nervous system, and less frequently in the intra-abdominal viscera. The most thorough studies, however, have been recently reported by Zuckerman (472, 473). This author exposed various experimental animals such as mice, rats, guinea pigs, rabbits, and monkeys, to explosions at varying distances from the charge. It was found that at certain distances the animals were immediately killed while further away there was a zone of pressure in which animals survived for periods varying between a minute and a day (473). These animals sometimes had blood-stained froth in the upper respiratory passages and afterward suffered from air-hunger, dyspnea, and tachypnea (473). However, some of the animals in which these manifestations appeared survived the twenty-four hour period and recovered completely. None of the animals exhibited external evidence of injury. Necropsy studies on these animals showed that the most prominent lesion was bilateral hemorrhage in both lungs varying in degree according to the distance of the animals from the charge. Similar lesions were occasionally observed in the intra-abdominal organs. The hemorrhagic lesions varied from pin-point spots on the lung surface to patches which in the very severe cases involved

the entire lung surface. Of particular interest was the fact that these hemorrhagic lesions frequently followed the rib lines. On section the lungs showed "confluent zones of hemorrhage" which in the less severe cases were scattered and sometimes related to large bronchi, but in the very severe cases the lungs appeared "hepatized." Blood was found in the nasopharynx, trachea, and bronchi in all animals that died of the blast injury. Of particular interest also were the anatomical sites of election of these lesions. It was found that the anterior borders of the lungs "between the front of the chest wall and the mediastinum, and the inferior borders, which become compressed in the costo-phrenic sinus" were most vulnerable. The mediastinal surface and particularly the azygos lobe were other frequent sites. Microscopic studies of these hemorrhagic lesions showed blood filling the alveoli and small bronchioles with disruption of the alveolar walls and capillaries as well as interstitial hemorrhage. Fat embolism which was reported by Robb-Smith (354) in 1 case was not observed in any of the animals in Zuckerman's experiments and not mentioned in the clinical post-mortem studies of others (141, 176, 177, 324).

In considering the factors responsible for these pulmonary hemorrhagic lesions Zuckerman (473) states that several hypotheses have been proposed. The first is "that the lesions are due to the lowering of alveolar pressure by the suction wave, acting through the respiratory passages, with the consequent rupture of the alveolar capillaries." Another is "that the lesions are caused by the 'sudden distention of the lungs with air' rather than by 'external pressure on the ribs'"; and the third possibility, advocated by Hooker (212), is "that the lung lesions are due to the impact of the pressure on the chest wall." That this last possibility is probably the correct one was demonstrated by the results of Zuckerman's experiments. He found that the animals "exposed to blast from the explosion of charges of hydrogen and oxygen in balloons showed that lesions are bilateral when the animals are placed some distance from the explosion, and mainly, if not entirely, unilateral when the animals are placed so close that one side shields the other . . ." and that "the lesions are on the side facing the explosion." He states further, "This fact (as well as the anatomical sites of election of the hemorrhages) suggested that the lesions are caused by the impact of the wave on the body wall. It could hardly be interpreted in any other way. For if blast affects the lung through the respiratory passages, either by reducing alveolar pressure or

by suddenly distending the alveoli with air, it is impossible to explain why animals placed close to the balloon explosion sustain damage to the lung only, and to the lung on the side facing the explosion." Further confirmation of this hypothesis was obtained by experiments in which rabbits that were thickly clothed in sponge rubber jackets received no pulmonary damage, or very slight damage when compared to the controls; and animals with only one side of the trunk clothed in this way suffered severe damage on the uncovered side when the explosion faced that side and no damage when the explosion faced the covered side.

In considering the practical significance of these experimental observations on blast as a factor in bombing and air-raid casualties Zuckerman (473) directs attention to the fact that "the circumstances . . . are very unlike the experimental conditions that have been described." For this reason a number of other factors may play significant roles in the production of these casualties and in their casualty survey it was found possible to classify the causes of injury into four groups:

I. "(a) Being hit by splinters; (b) being affected by the impact of the blast wave (e.g. effects on the lungs and ears); (c) being burnt by the flame of the explosion; (d) (possibly) being poisoned by carbon monoxide liberated by the explosion in enclosed spaces; and (e) (possibly) in the remote chance, being hit by the bomb itself.

II. "(a) Being thrown by the blast wave against a hard surface; (b) being bowled over as a result of a splinter wound.

III. "(a) Being hit by secondary missiles, e.g., flying masonry, wood, furniture, glass, girders; (b) having walls, floors, ceilings fall on one, either as an immediate effect of an explosion or as a result of collapse due to an earth shock wave; burial under débris; in steel shelters, being crushed by the caving-in of the shelter; (c) falling, through being knocked, other than directly by blast, from a raised position, or through collapse of a floor; and (d) (possibly) the impact of an underground wall violently accelerated, but not broken by an earth shock wave.

IV. "(a) Asphyxiation; (b) carbon monoxide poisoning; (c) burns; and (d) drowning."

After considering these various factors it is reasonable to assume that blast injuries incurred under circumstances similar to those of the experiments will be relatively infrequent. However, various degrees of injuries and even fatalities following blast have been reported. Falla (141) reported a case in which the patient was injured

by a bomb exploding in the workshop about 45 ft. away and died twelve hours later. At necropsy characteristic hemorrhagic lesions were found in the lungs. A somewhat similar case was described by Osborn (324). An analysis of 27 cases was recently presented by Dean, Thomas, and Allison (105). Severe blast was experienced in all but 2 patients. The significance of the factors described, other than the blast, is demonstrated by this series, for extensive superficial burns were present in 21, fractures in 5, and multiple splinter wounds in 1, and 3 patients were immersed in the sea. Symptoms referable to the chest were present in only 6 patients and these consisted of cough and expectoration, which appeared between the second and fifth days. The abnormal physical signs in the chest, present in 16 of the patients, consisted briefly of decreased diaphragmatic movement; a "ballooned" appearance or fullness of the chest, especially of the lower part, suggesting an emphysema; and impaired resonance. Roentgenographic examination showed abnormalities in 14 of the cases and in most of these the changes were similar to "an early pleurisy—a diminution of rib-expansion on the affected side, together with slight loss of translucency" (105).

The influence of the other factors enumerated in blast injuries is further demonstrated in the report of Hadfield and his coworkers (177). These investigators studied 10 cases in which circumstantial evidence pointed to death being due to "blast." In all but 1 case gross traumatic lesions were completely absent or the lesions were of trivial degree. All of the cases showed some degree of intrapulmonary capillary hemorrhage. Two patients who were extricated from overlying débris were first considered suffering from "blast" injury but subsequent examination revealed that death was due to compression asphyxia. The hemorrhagic lesions in these patients were relatively slight. In 3 cases the blood was found to be saturated with a fatal degree of carbon monoxide. Pulmonary hemorrhages were present in these cases also but there was a "fresh pink colour of the hypostasis." The remaining patients presumably "died from the effects of 'blast,'" and exhibited "free capillary bleeding over large areas in which the respiratory bronchioles, atria, and alveoli showed uniform and considerable overdistention."

It is obvious from the foregoing discussion that there are a number of significant factors in the cause of death of patients who have been exposed to the detonation of high explosives. This is emphasized by Zuckerman (473) who states, "fatal casualties with little or no external signs



of injury will probably only in rare instances have died from the direct effects of blast alone. Other causes of death in such circumstances are asphyxia following burial under débris, carbon monoxide poisoning, and death from chronic diseases aggravated by sudden shock. Whether blast alone can cause death as a result of nervous crisis is a matter which at present is only open to speculation." Moreover, it should be realized that "bruising of the lungs may occur not only as a result of the direct action of blast, but also as a result of secondary and tertiary blast effects such as violent displacement, and the impact of flying and falling masonry."

Although characteristic pulmonary lesions were demonstrable both in the experimental animals and in patients who died immediately or shortly following the blast of explosions, no satisfactory explanation of the cause of death was always determinable. Zuckerman states, "pulmonary lesions cannot always be regarded as responsible." In this connection Hadfield (175) emphasizes the significance of the observation based upon 30 post-mortem studies, that there existed a "disproportion between the amount of blood in the alveoli and the relatively slight damage to the alveolar walls themselves." There was also observed a marked dilatation and congestion of the alveolar capillaries as well as of the alveolar ducts and bronchioles. However, according to Hadfield this may indicate that possibly much of the intrapulmonary capillary bleeding is due to diapedesis and that hemorrhage may continue for a considerable period of time following the accident. Accordingly the variations in degree of intrapulmonary hemorrhage may be explained by the period of survival. In 1 case reported by Hadfield and Christie (176) the bleeding continued for fifty-one hours. According to Hadfield (175) this observation is of therapeutic significance for it means that these patients should be immobilized as if they had had a recent large hemoptysis, and it may be that disregard of this precaution may explain why some, who have been exposed to detonation and have apparently recovered from the initial respiratory embarrassment, have subsequently had a relapse. A pneumonic process subsequently developing in some of the cases was also observed by Hadfield (175) and O'Reilly (322).

It may be readily observed that in the therapeutic management of these cases one is immediately confronted with a number of difficulties. Shock is almost invariably present and in addition to the pulmonary disturbances there are frequently other associated injuries, such as exten-

sive burns, fractures, carbon-monoxide poisoning, and injuries to the intra-abdominal viscera and central nervous system. Because of the intrapulmonary hemorrhages and the possibility of furthering this bleeding by the usual procedures of resuscitation, great care must be exercised in applying these therapeutic measures. The significance of this lies in the fact that the accompanying shock may be attributed to other injuries since the clinical manifestations of pulmonary damage in blast injuries are frequently delayed for several days. For this reason blast injury of the lungs should always be suspected in such cases and the patient treated accordingly. It is probably desirable not to employ the Schafer method of artificial respiration for asphyxia in these patients (122). It has been suggested that morphine should be used cautiously and in small doses ( $\frac{1}{8}$  gr.) to allay restlessness (123). On the other hand, Whitty (461) takes exception to this because "it is not a sound principle of therapy to deny the full use of a unique and advantageous drug unless its incidental deleterious effects cannot be avoided or controlled." Since this is possible by the administration of "oxygen, carbon dioxide and other respiratory stimulants" one is inclined to agree with Whitty (461) that the use of full doses of morphine to relieve pain and restlessness is rational. In view of the experimental and clinical observations on the lung changes these patients "should be rested as strictly as if they had had recent severe haemoptysis" (176); and the inestimable value of morphine for this purpose has long been recognized. The importance of absolute rest in these patients is further illustrated by the case reported by Hadfield and Christie (176). This patient had shown considerable improvement thirty-six hours after the accident and was considered fit for transportation. However, the movement consequent to the journey by ambulance caused the patient's condition to become considerably worse. Transfusions of whole blood, plasma, or other fluids may be better withheld in the early stages because of the risk of inducing pulmonary edema, and shock should be combated by the institution of other methods which stimulate the peripheral circulation (123, 364). Because of the acute pulmonary congestion Hadfield and Christie (176) consider venesection and the use of concentrated serum as possible procedures. Posture is also considered important and the best position is probably with the shoulders raised (123). In those cases with evidence of unilateral contusion the patient should be placed so that he lies on the contused side to prevent aspiration into the normal lung. If it

becomes necessary to employ a procedure in which an anesthetic is required, a local or intravenous type is preferable (123, 356, 364). The treatment of the lung injury is "mostly symptomatic and not unlike that of pneumonia—the administration of morphine and heat for pain, of expectorant mixtures for cough, of oxygen for cyanosis, and the usual general nursing care. Sulphapyridine may be useful in preventing infection of the damaged areas" (364). Obviously associated injuries such as fractures, extensive burns, and carbon-monoxide poisoning will require appropriate therapy but the pulmonary lesion must be kept in mind and methods employed which will not aggravate this condition.

As previously stated penetrating wounds of the chest are far more frequent than the non-penetrating types. This is true particularly of injuries inflicted during warfare. Moreover this type of chest wound, in general, is far more serious than the non-penetrating variety. This is due to the fact that the former is more likely to be complicated by greater disturbance in the cardio-respiratory physiology, by extensive tissue damage, by retention of a foreign body, and by consequent infection. For this reason operative intervention is more frequently indicated. However, because shock is almost invariably present, and this is true especially in war wounds, even urgent operation must be delayed. Except in cases of open pneumothorax and hemorrhage from a parietal wound, operative therapeutic procedures should not be instituted until the patient has recovered from shock. The management of shock in these conditions has been considered.

While it is convenient to classify penetrating wounds of the chest into those that are limited to the chest wall and those that involve the pleura and intrathoracic structures, not infrequently this distinction is difficult to make. For this reason considerable care in the examination and observation of the patients must be exercised. Although during the period of shock this examination must be limited and the patient allowed to rest as much as possible, he should be watched closely to determine any evidence of deterioration in his general condition that would indicate continuous intrathoracic hemorrhage or serious visceral damage. A careful clinical history is essential in ascertaining the extent of the injury. Various agents such as knife blades, ice picks, rifle bullets, bomb splinters, shrapnel, and shell fragments produce characteristic lesions with varying degrees of tissue damage. The site of entrance and exit, and knowledge of the direction of the inflicting agent facilitate determination of

the organs injured and the possible extent of tissue damage. In this connection it should be realized that for various purposes, such as the avoidance of military service, penetrating chest wounds may be self-inflicted and simulated (17). In addition to the clinical history, a careful physical examination should be made with particular attention to signs indicating the presence of air or fluid in the pleural cavity, and frequent determinations of the temperature, pulse rate, blood pressure, and the apex beat of the heart are essential. As soon as the patient's condition permits, roentgenographic studies should be performed. The value of such studies in determining the presence and location of retained foreign bodies, and in confirming mediastinal displacement, pneumothorax, hemothorax, intrapericardial tamponade, and contralateral collapse of the lung has been repeatedly emphasized. Such studies should be made in the erect posture.

Penetrating wounds of the chest wall which do not involve the pleural cavity are usually of no serious consequences. However, because of the possibility that the pleura may be perforated they should be carefully explored. In general, such wounds are produced by spent missiles, tangential impact of various projectiles, and occasionally by a blunt crushing force. They may consist of simple punctures or incised wounds or may be complicated by considerable laceration of muscle tissue and by fractures of the ribs, sternum, clavicle, or scapula. Occasionally they are produced by bullets which are deflected along a rib. In general the management of these wounds is similar to those in other parts of the body. This consists essentially in thorough cleansing, excision of devitalized tissue, and primary repair if therapy can be instituted in the first six or eight hours, i.e., before infection has developed. Every attempt should be made to avoid opening of the pleura and to protect it from infection. Wounds in the back of the chest are more likely to be associated with greater tissue damage than wounds of the anterior part of the chest. This is due to the greater musculature of this area and the presence of fascial planes which permit extension of blood and infection. For this reason considerable care must be exercised in the excision of lacerated and devitalized muscle tissue in these regions and the prevention of deeply placed anaerobic infection (15, 73). In the presence of compound fractures, wide excision of damaged tissue and removal of loose fragments of ribs may be necessary. Damaged intercostal vessels which are usually associated with rib fracture should be carefully ligated. Sometimes these vessels are damaged between the

bodies of the vertebræ and the angle of the ribs where they are not so intimately associated with the ribs. In such instances hemorrhage may occur from these vessels in the absence of rib fracture. For this reason, thoracotomy occasionally is necessary in controlling hemorrhage from these vessels as well as in controlling hemorrhage from the internal mammary vessels. Fatal hemorrhage from an intercostal vessel has been reported (101). Compound fractures of ribs are usually associated with pleural penetration and for this reason thoracotomy in such cases becomes necessary to determine the possibility of lung injury by an indriven rib fragment.

Wounds, especially those occurring in warfare, which involve only the thoracic parietes comprise about 10 per cent of chest injuries according to Yates (469). In another 10 per cent, visceral injuries are produced without penetration of the chest wall. Visceral injury associated with penetrating wounds comprise the remaining 80 per cent. Accordingly, penetrating wounds of the chest are most frequently complicated by intrathoracic injury. Such penetrating wounds may be of the so-called "closed" types or open forms. The former type is produced by an ice pick, knife blade, or bullet. The wounds are usually characterized by a small opening which is readily closed or sealed by the surrounding soft tissue. While the wound in the chest wall may require little attention, the intrathoracic injury may be quite serious. In the management of these wounds attention must be directed toward the complications which may be produced by injury to the lungs, heart, large vessels, and other structures in the mediastinum. The complications produced by such injuries consist of emphysema, pneumothorax, hemorrhage, hemothorax and hemopneumothorax, and intrapericardial tamponade. In addition to these complications there may be lacerated lung tissue, retained foreign bodies, and consequent infection.

Although such complications may also be associated with so-called open chest wounds their management differs from that required in the "closed" type of wound in that the wound of the chest wall requires immediate attention. Such wounds may be of the "valvular" type or may be of the open pneumothorax form. In the former the entrance of air is permitted during inspiration but its escape is prevented during expiration. This leads to the rapid development of tension pneumothorax and requires immediate attention. In the open pneumothorax type the defect in the chest wall is of sufficient size to permit the entrance of air and blood into the pleural cavity

during inspiration and their escape during expiration. This causes rapid collapse of the homolateral lung and because of the mediastinal flutter, collapse of the contralateral lung, which results in a marked decrease of vital capacity. Of interest in this connection is a case of open pneumothorax reported by Kroemer (236) in which there was herniation of the lung with blockage of the wound, a condition usually denied. The striking train of symptoms which follows open pneumothorax is too well known to require detailed description. Suffice it to say that the marked dyspnea and rapid, often irregular, labored breathing, cyanosis, coldness, irregular feeble pulse, decreasing blood pressure, and other signs of shock associated with a sucking wound form an alarming clinical picture, and death appears imminent. Obviously treatment is urgent and this consists simply in the immediate closure of the wound. In this connection it is an interesting fact, familiar to all thoracic surgeons, that an open pneumothorax under certain conditions such as in surgical thoracotomy is not dangerous in man. Yet in these traumatic injuries serious manifestations occur. According to Barrett (15) this is explained by "the fact that in man, during quiet respiration, an open pneumothorax does not embarrass the circulation or the respiration beyond the points of their reserve. If the burden of shock, painful respiration, haemorrhage, bronchial obstruction (by blood or secretions), or sepsis is added to an open pneumothorax the load is too great and the result is immediately serious." The gravity of these wounds is demonstrated by the fact that in a series of 18 cases observed by Lilienthal (258) during the last World War there was a mortality of 34 per cent, "a larger death rate than in any other class of thoracic wounds." Various methods have been suggested for the emergency closure of such wounds, consisting essentially of either suture or tamponade (241). The insertion of sponges and fixed dressings is condemned by Achutin (1). Ideally such wounds should be closed by thorough cleansing, removal of foreign bodies and débris, wide excision of devitalized tissue, and primary suture. However, primary surgical closure should not be attempted except in the first few hours after the injury. This is frequently not possible during this early period, and yet immediate closure is urgent. Barrett (15) states that the "best way to close an open pneumothorax in an emergency is to cover the wound with a pad and it is convenient to carry a standard dressing for this purpose; it consists of a piece of mackintosh tissue to one side of which several layers of vaseline gauze have been sewn. This dressing should be

strapped over the wound." A somewhat similar method is advocated by Frey (153) who states that in the German army a water-proofed dressing is placed in the pocket of every ambulance man. Similarly in the Spanish War, Kretzschmar (233) states that a provisional dressing of air-tight oiled silk and elastoplast was provided. Hailes (178) emphasizes the importance of suturing the dressing of multi-layered gauze to the wound edges as the only means of adequately keeping the dressing in place during stretcher transport. During the last World War, the Italian surgeons (17, 18, 295) advocated the use of a dumbbell-shaped rubber bag which after insertion into the wound was inflated, and thus effected hermetic closure. Tiegel (427) has devised a valve drainage plate which may be applied to the wound, thus permitting immediate closure as well as drainage to prevent the development of hemothorax and tension pneumothorax. Subcutaneous pneumopexy or suture of the lung to the wound edges as recommended by some (90, 128) is condemned by Frey (153).

Those cases of open pneumothorax in which emergency closure has been effected by sterile air-tight dressings, if seen early enough after injury, can still be treated by primary suture. In this connection Barrett (15) emphasizes certain features concerning the suture of these wounds which are particularly important from the military aspect. He states that while in general the suture "can include both muscles and skin after efficient and early excision," this procedure "does not apply to patients who have to be evacuated soon after operation, with the possibility of a journey of several days without careful supervision." For this reason, "it is wise to sew the muscles over the defect but not the skin, and to cover the wound with a pad and strapping. Delayed primary suture can then be done at the base hospital." Following primary suture, according to Barrett (15), intercostal closed water-sealed drainage of the pleural cavity for at least forty-eight hours is essential. If at the end of this time microscopic examination of the fluid reveals no micro-organisms the drainage tube may be removed. On the other hand, if organisms are present drainage must be maintained. However, the advantage of this procedure lies in the fact that the original wound is allowed to heal while an empyema may be developing. Not infrequently these patients are obtained at a stage when primary suture is contraindicated. This is due to the fact that after about eight hours, infection is already established or very likely to develop. However, as emphasized by Barrett (15), in such an instance "the wound must be left surgically open, so that pus and

exudate can escape, but closed with an air-tight dressing." He directs attention to the danger of sewing the muscles or the skin over the defect because "it engenders sepsis in the chest wall as well as in the pleura." In such cases intercostal drainage is necessary and after "the patient has overcome the superficial infection the sucking wound should be treated by secondary suture, an operation which can be undertaken in the presence of a properly drained empyema."

In the "valvular" type of chest wound immediate closure is also indicated, and the tension pneumothorax which may be present after closure in this type, as well as in the open pneumothorax type, should be managed as previously described. If water-sealed drainage is done in the latter type, as is usually advocated, tension pneumothorax will be obviated.

As previously emphasized in both the so-called closed penetrating chest wounds as well as in the open wounds the injury to the chest wall is in the great majority of cases accompanied by varying degrees of injury to the intrathoracic structures. Accordingly, in any type of penetrating chest injury it is important to determine the presence of pleuropulmonary lesions, cardiac lesions, and injuries to the hilar vessels and mediastinal structures, as well as to the diaphragm and subphrenic structures. According to the structures involved and the extent of damage produced, the resultant manifestations will be reflected by the occurrence of certain complications such as emphysema, tension pneumothorax, hemorrhage with consequent hemothorax, hemopneumothorax, intrapericardial tamponade, and later infection. As has been previously emphasized the presence of these complications causes marked disturbances in cardiorespiratory physiology. Moreover, it is this factor which makes the difference in the management of chest wounds as compared to wounds in other parts of the body. Accordingly, in the management of penetrating chest wounds, as in the non-penetrating type, therapeutic considerations must be focused on the management of these complications.

In general the management of these chest wounds and their different complications can be divided into conservative and radical therapy. The indications of each depend upon a number of factors. Thus penetrating chest wounds occurring in civil practice are in general more readily adaptable to conservative management because they are most commonly of the stab wound or "closed" penetrating type in which extensive tissue injury, disturbances in cardiorespiratory physiology, and development of infection are

minimal. On the other hand, operative intervention is more frequently necessary in war wounds of the chest because they are produced most commonly by such agents which cause extensive tissue damage with greater hemorrhage, disturbances in the cardiorespiratory physiology with the likelihood of a retained foreign body, and infection.

Subcutaneous emphysema and pneumothorax are frequent complications of penetrating chest wounds. In Elkin's (130) series of 553 civil cases the former occurred in 40 per cent and the latter in 24 per cent. The corresponding incidences in Boland's (50) series of 1,009 cases were 15 per cent and 19 per cent. Conners and Stenbuck (90, 408) in an analysis of 68 cases observed subcutaneous emphysema in 40 per cent. Fortunately, however, in the majority of cases, unless associated with serious injury, they are of no grave consequences. Mediastinal emphysema if severe may produce alarming manifestations. Its treatment is similar to that described in connection with non-penetrating injuries. Similarly, tension pneumothorax should be managed as previously considered. If associated with valvular wounds this should be promptly closed and tension relieved by aspiration of air from the pleural cavity. Occasionally air continues to enter the pleural cavity and water-sealed drainage may be necessary. In bilateral tension pneumothorax aspiration of both pleural cavities is required.

Hemothorax is one of the most frequent complications of penetrating chest wounds. Although hemothorax may be due to hemorrhage from a number of sources, the injured lung is probably the most common (56, 59). Of interest in this connection is a case of gunshot wound of the chest in a patient with artificial pneumothorax and complete collapse of the lung which existed prior to the injury (326). It was found that the "bullet traversed only the chest wall and the pneumothorax cavity, there being no significant injuries other than the rib fractures" (326). Hemothorax was present in 37 per cent of Elkin's (130) series, in 25 per cent of Boland's (50, 51) series, and in 36.7 per cent of Steinke's (407) series. It should be remembered, however, that these are civil wounds and that the incidence in war wounds is probably much greater (59, 367). During the last World War in a series of 115 cases admitted to one of the Evacuation Hospitals of the American Expeditionary Forces pure hemothorax occurred in 94 (81 per cent) (207). The factors which influence the cause and management of hemothorax previously discussed in connection with non-penetrating chest wounds are applicable to hemothorax complicating pene-

trating wounds. However, the danger of infection in the latter, especially in war wounds, is greater. As previously stated there is still some controversy regarding the management of traumatic hemothorax with opinions varying between ultraconservatism and radical operation. There is fairly general accord that moderate hemothorax in so-called closed penetrating chest wounds occurring in civil life should be treated conservatively. In contrast to these more conservative views on the management of such injuries, Schrire (383) in a recent consideration of the subject is inclined to radical therapy even in stab wounds, occurring in civil practice. He states that unless the condition of the patient was so bad as to render any operative intervention an entirely hopeless procedure, every patient with a penetrating wound of the chest admitted under his care was subjected to an exploratory thoracotomy as an emergency measure if seen within twelve hours of the injury. Aspiration is usually delayed unless dyspnea becomes manifest. Others advocate immediate aspiration with air replacement. Allen (4) suggested that a simpler way of removing the blood from the pleural cavity than by aspiration is to close the wound in the chest wall and have the patient "lie with the closed hole down in the most dependent position," thus permitting gradual leakage of the hemothorax. More recently Nicolosi (304) and Caldarrera (79) have recommended alcoholization of the intercostal nerves in these cases as originally suggested by Latteri (243), in 1933, in an attempt to limit movement of the injured lung and chest and thus control the hemorrhage. That the conservative method of therapy is suitable for hemothorax occurring in civil wounds of the chest is shown by the relatively low mortality rates reported by various authors. The mortality following this method of therapy was 6 per cent in Elkin's (130) series and 4.3 per cent in Cato and Norman's (80) series. Moreover, the incidence of infection in these cases was extremely low (133).

On the other hand, in penetrating war wounds of the chest operative intervention will be more frequently indicated. This is reflected in the writings of a number of surgeons whose experience in the last World War led them toward this conclusion (5, 16, 111, 115-119, 134, 157-160, 169, 171, 192, 205, 217, 262, 264, 357, 469). Duval (119) states that up to August, 1916, such wounds were not treated by operation and the general mortality, not including "a large number of deaths which occurred in the advanced posts and in the base hospital," was 30 per cent. The two most important factors in this high mortality

were hemorrhage and infection. As has been previously emphasized, infection is much more significant in war wounds than in civil wounds, and was primarily responsible for the tendency toward operative intervention in the latter part of the war. In an analysis of 115 cases of penetrating chest wounds which occurred during the last World War, Heuer and his coworkers (206) found that 20 per cent were infected. Similarly Bradford (55, 56) and Bradford and Elliott (59) in a study of 170 cases found this incidence to be about 37 per cent, and Shipley (394) recorded an incidence of 40 per cent in 100 cases. That this is also an important consideration in the present conflict is shown by Livingstone (261) who reports that, "of 115 cases of haemothorax seen recently, 30 per cent were infected." Following the more radical form of therapy used during the latter part of the last World War, Duval (119) states that the mortality decreased to 9 per cent. On this basis he concluded that "surgical treatment of the lung should, therefore, be considered as the logical prophylactic procedure to prevent sepsis." A similar opinion was expressed by Gask (157) who in commenting upon the fact that infection was one of the most important considerations in these wounds stated that "the principle, therefore to be aimed at is the early mechanical cleansing of the wound, both of the chest wall and of the injured viscera, the evacuation of all foreign bodies and of effused blood from the pleural cavity, the repair or suture of the damaged lung and the closure of the chest cavity by suture." As regards the significance of foreign bodies Turner (437) states, "After four years' experience of war surgery, I am more and more impressed with the general truth of the proposition that sooner or later a foreign body wherever situated, tends to give rise to trouble." Similar observations have been made by others (148, 232, 251). The indications for early operation as presented by Duval and Gask (115-119, 157-159), in addition to certain types of wounds of the chest wall previously considered, include large hemothorax which cannot be evacuated by aspiration, probably because of massive clotting, the retention of large foreign bodies within the chest, and "every wound of the lung which on fluoroscopic examination shows a large intrapulmonary haematoma." More recently Mitchiner and Cowell (290) concurred with Gask and Duval on these indications. Similarly Thomas (423) in a consideration of this subject stated that "definite indications for operative intervention during the six hour interval" consisted of: "(1) Wounds producing an open pneumothorax, more graphically called sucking wounds;

(2) haemorrhage which is overt and progressing; (3) haemothorax with a retained foreign body; (4) haemothorax where there is reason to suspect, from the direction of the injury, the position of the foreign body or other radiological or clinical evidence, that the diaphragm, heart or pericardium has been injured." In other recent contributions to this subject somewhat similar views have been expressed (69, 178, 200, 233, 293, 302, 308, 355, 357, 358, 429, 440). From the foregoing discussion it would seem that operative intervention is not indicated in these cases in the presence of through-and-through wounds caused by rifle bullets producing small clean wounds of the chest wall with little hemorrhage, in cases having no rib fracture, and if the retained foreign body is small (115-119, 157-159, 422, 423). However, as emphasized by Thomas (423), "there will be many borderline cases which will be dealt with at the discretion of the individual surgeon." The advantage of early intervention especially in progressive massive hemorrhage has been recently dramatically demonstrated by Monod (292), who reported 2 cases of perforating chest wounds due to pistol bullets. In both cases, which were suicidal attempts, there was injury to one of the large pulmonary veins, and the operation, consisting of lobectomy and performed within forty-five minutes after the injury, resulted in recovery. A somewhat similar case has been reported by Whitaker (460) in which the stab wound involved the left superior pulmonary vein. Operation in this case consisting of thoracotomy, exposure of the lacerated vein, and closure of the opening in the vein was also successful. Obviously such heroic procedures would be practically impossible to apply in war wounds.

No attempt will be made here to discuss technical considerations of operative intervention in these cases as they have been adequately presented in previous publications (94, 115-119, 157-160, 206, 264, 290, 357, 422, 423, 469). Suffice it to say that these consist essentially of thorough surgical revision of the wounds of entry and exit with removal of all loose rib fragments and devitalized tissue. While thoracotomy may be performed through one of these wounds if conveniently situated, ample exposure is important and exploration through a poorly placed incision should be avoided. The pleural cavity must be emptied of all blood and clots and a careful search made for retained foreign bodies and injury of the intrathoracic structures. In diaphragmatic wounds the subdiaphragmatic area should be carefully examined by enlarging the wound radially. Following necessary corrective procedures within

the chest the wound in the chest wall is carefully closed and intercostal catheter water-sealed drainage instituted. If there is no evidence of infection the tube may be removed in from forty-eight to seventy-two hours.

Infected hemothorax forms one of the most frequent complications of penetrating chest wounds occurring in warfare. This is due to the fact that in such injuries tissue damage is likely to be more extensive and dirt, débris, bits of clothing, shell fragments, and other foreign bodies are more apt to be carried and retained in the chest. The gas bacillus, streptococcus hemolyticus, streptococcus viridans, staphylococcus, and pneumococcus are the predominating organisms (136, 206, 217, 357). The characteristic clinical manifestations consist of high fever, chest pain, dyspnea, tachycardia, restlessness, and other evidences of toxemia. In anaerobic infections the clinical picture is much more striking (136). The patient appears seriously ill within a relatively short time. Dyspnea, tachycardia, and thoracic pain become marked and anxiety apparent. Restlessness may progress to actual delirium. The cheeks appear flushed and an icteric conjunctival tint or even actual jaundice are frequent. Evidence of gas within the chest becomes obvious and is frequently under unusually high pressure (136). The relative frequency of anaerobic infection in war wounds of the chest is shown by the statistics of Elliott and Henry (135, 136), based on cases occurring during the last World War. They found that in 195 (39 per cent) of the first 500 specimens of hemothorax infection was present and of this number 87 (17.4 per cent) were due to anaerobic organisms. An excellent consideration of this subject is presented by these authors.

As previously emphasized early diagnosis of infection in hemothorax is essential and delay until characteristic manifestations become apparent should be avoided. For this reason the presence of infection should be determined by careful examination of the aspirated fluid by gross appearance, odor, smear, and culture studies. Once the diagnosis has been established prompt and appropriate therapy should be instituted as previously considered. In anaerobic infections, Elliott and Henry (136) state that the ideal method of treatment should aim at removing the gas, infected fluid, septic blood clots, and foreign bodies; extinction of the infecting organisms; and inducing rapid re-expansion of the collapsed lung. However, they sadly admit that in actual practice "this complete ideal has not been attained;" but open drainage is necessary, and clots and foreign bodies, if accessible, should be removed.

The use of sulfonamide drugs in the prevention and treatment of infections in these chest injuries has been receiving increasing attention. Schrire (383) believes that "this has had a considerable effect in reducing the incidence of infection." Herrell and Brown (204) in an investigation of the local use of sulfamido compounds in the treatment of infected wounds obtained results which were "exceedingly encouraging in the treatment of wounds involving the thoracic cavity." In their opinion the best method of application consists in the use of a thick suspension prepared by adding 2 gm. of powdered sulfanilamide to 100 c.c. of an 0.8 per cent solution of sulfanilamide in normal saline solution. This suspension should be instilled into the wound or pleural cavity thrice daily. In a recent discussion of war wounds of the chest Livingstone (261) directs attention to the value of sulfonamides and states that they have used sulfapyridine principally, both for prophylaxis and treatment, in view of the possibility of pneumococcal infection. Tubbs (435) refers to a case of thoraco-abdominal injury in which clostridium welchii organisms were present and intensive chemotherapy was employed. He states that the sulfanilamide modified but did not abort the infection. Jeffrey (219) has recently presented a detailed discussion of the therapeutic use of sulfonamides in war wounds occurring in the current European conflict. According to this author the local application of sulfonamides either in an emulsified form or by spray was more beneficial than the oral administration. He states that Colonel Colebrook of the B. E. F. had supplies of the powder available at the casualty clearing stations and base hospitals with the idea that it might be of value in (1) those cases in which débridement and primary suture could be performed and in which débridement must be less radical than is desirable; (2) in accelerating the healing of septic wounds; and (3) in possibly permitting primary suture at a relatively late period, i.e., from twenty-four to forty-eight hours after the injury, if the drug was applied on the battlefield at the field ambulance. In the cases with entry and exit wounds the track was incised, cleaned of devitalized tissue and foreign bodies, and packed with sulfonamide. Unfortunately, few cases of intrathoracic injuries were available for statistical study. In their recent consideration of war wounds of the chest Roberts and Tubbs (358) state that up to the present, "the evidence favors a diminution in the incidence of infection and a decrease in the severity of toxemia when infection does arise as a result of the prophylactic use of the sulfonamide drugs." In his discussion of wound

sepsis in thoracic surgery Hart (191) states that "at the present state of our knowledge of sulfonamides a suitable one of these should be sprinkled in the wound to inhibit bacterial growth." Gask (159) has recently summarized the present attitude toward chemotherapy in war wounds. In the consideration of sulfonamides for this purpose he admits that their value cannot be accurately estimated nor is it possible to determine "how far or how successfully sulfanilamide can be used prophylactically to prevent infection occurring in wounds . . . . Nevertheless, it may be said that there is a general impression among surgeons, who have used it in the recent air raids, that it is of real value and, if used intelligently, may supplement, although not replace, mechanical cleansing of wounds." Similar views have been expressed by numerous other observers both in civil and war surgery (54, 78, 87, 147, 154, 155, 193, 226, 252, 256, 289, 318, 342).

Penetrating wounds of the heart which have surgical significance occur relatively rarely. This is probably due to the fact that such wounds especially in warfare are almost immediately fatal. Even in civil practice their incidence in chest wounds that reach the hospital is very low. Bigger (39) reports an incidence of 0.1 per cent among surgical patients at the Medical College of Virginia Hospitals, and Elkin (130-133) states that their incidence is about 2 per cent in penetrating wounds of the chest. In Boland's series (50) of 1,187 cases of penetrating chest wounds at the Grady Hospital in Atlanta there were only 16 (1.4 per cent) cases of heart injuries. The majority of these wounds amenable to surgical intervention are stab wounds produced by a knife blade or an ice pick. Gunshot wounds are almost invariably fatal although cases have been recorded in which the patient has recovered and a bullet had remained in the heart for periods varying from several years to more than twenty years (138, 144, 203, 250, 344, 416, 438, 439). Decker (106) has recently presented an extensive review of the literature on this subject and summarized the results of 109 collected cases of foreign bodies in the heart and pericardium. The characteristic clinical manifestations produced by penetrating wounds of the heart which are not immediately fatal are the result of cardiac tamponade. A detailed discussion of these features will not be attempted here as they have been adequately presented in a number of recent publications (36-41, 97, 131, 341, 452). Briefly the mechanism of cardiac tamponade is based on the rapid disturbances in intrapericardial pressure relationships following a penetrating wound of

the myocardium. Because of the limited distensibility of the pericardium, as blood accumulates in the pericardial cavity the intrapericardial pressure rapidly rises to a point which soon affects the filling and emptying of the heart and unless promptly relieved will quickly cause cessation of the cardiac function. The train of symptoms which follow cardiac tamponade are quite characteristic and consist essentially of weak heart sounds and peripheral pulse, decreasing arterial pressure, increasing venous pressure, unconsciousness due to cerebral anemia, prominence of the veins, especially those of the neck, and cyanosis particularly of the face, lips, and tongue. In addition to these manifestations, and the history, position and direction of the wound the diagnosis is further supported by fluoroscopic examination (37, 41) which reveals diminution in cardiac pulsation.

For purposes of convenience in the management of these cases Mayer (280) and Bigger (39) classify these heart injuries into four groups:

1. Patients with definite cardiac injury but with slight or moderate intrapericardial or intrapleural hemorrhage. In such cases the wound may involve the wall of the heart as well as the pericardium but without complete penetration into the cardiac chambers. Acute cardiac tamponade is usually absent and conservative management is sufficient.

2. Patients with definite cardiac tamponade which is satisfactorily relieved by conservative measures. However, if after pericardial aspiration there is evidence of recurring hemorrhage, operative intervention should be instituted.

3. Patients with rapidly developing severe tamponade which does not respond to conservative measures and in which prompt operative intervention is required.

4. Patients with massive intrapericardial and intrapleural hemorrhage. While operation should be done immediately in these patients the procedure is usually futile.

In the majority of penetrating wounds of the heart prompt operative intervention will be necessary. Bigger (40) estimates that about one-fifth of the cases are suitable for conservative treatment. This consists essentially of supportive measures such as morphine, transfusions, and other measures to combat shock and of aspiration of blood from the pericardial cavity to relieve tamponade. A number of cases have been reported in which this form of therapy was successfully applied (40, 398, 413). In those cases in which operative intervention is clearly indicated, the procedure, consisting essentially of cardi-



rhaphy, should be performed as soon as possible. Occasionally the injury involves the pericardium only, but because of the possibility of hemorrhage from the pericardiophrenic artery operation is necessary (257). Adequate exposure is essential and various approaches have been advocated (11, 103, 120, 288, 405). Technical considerations in exposure and suture of wounds of the heart will not be discussed as they have been adequately described in numerous publications (23, 36-41, 131, 132, 274, 277, 343, 382, 403, 439).

It is indeed gratifying to observe the ever-increasing number of surgically treated heart wounds and the steady decrease in operative mortality. In 1937 Ludlum and Katz (267) were able to collect 423 cases in which operation was performed. Approximately thirty years ago the mortality incidence was over 60 per cent (335), but recently a number of reports have appeared in which this incidence varied from about 35 per cent to 40 per cent (40, 132). Moreover, the late results in cardiorrhaphy are good even in cases necessitating ligation of branches of the coronary artery (291, 319).

Penetrating wounds of the chest involving other mediastinal structures such as the large vessels, trachea and main bronchi, esophagus and thoracic duct are extremely serious and usually fatal. Such injuries are characterized by massive hemothorax or hemopneumothorax, extensive and alarming mediastinal emphysema, chylothorax, and, in those cases which survive the immediate trauma, mediastinitis. Injuries of the large vessels producing progressive and massive hemothorax require prompt surgical intervention. Similarly, perforating wounds of the trachea and main bronchi demand operative therapy. Relief of mediastinal emphysema is urgently required and may be obtained by cervical incisions as previously described or possibly by tracheotomy in cases of tracheal injury. However, the best results will probably be obtained by attacking the source. Injuries of the esophagus are rarely the result of penetrating wounds of the chest but most commonly follow instrumentation or the swallowing of sharp foreign bodies. In perforations of the esophagus following penetrating chest wounds immediate surgical intervention is indicated. The wound should be carefully débrided and repaired and drainage instituted. The various approaches to the thoracic esophagus have been previously described (313, 315). The principle danger in such injuries is infection and the rapid development of mediastinitis. As previously emphasized (311) in such instances prompt institution of a drainage is imperative "because most of these

infections are anaerobic, and the institution of drainage not only permits the evacuation of its contents but also produces aerobiosis. In cases in which there is infection with anaerobic organisms, irrigation of the wound with oxidizing agents is important." The various techniques of mediastinotomy for instituting drainage in these cases have been described (75, 303, 311, 334).

Injuries of the thoracic duct are manifest by the escape of chyle and the production of chylothorax. A number of excellent reviews on traumatic chylothorax have appeared in the literature and only a succinct consideration of the subject will be presented here (70, 102, 167, 189, 259, 270, 298, 391, 412, 443, 470). According to these reports traumatic chylothorax occurs relatively rarely. Thus, in 1912, Zesas (470) was able to collect only 18 recorded cases. Twenty years later Macnab and Scarlett (270) brought this total up to 34 cases. In 1935 Lillie and Fox (259) reported the forty-sixth case and since then there have been a few more (81, 163, 167, 279). Injury to the thoracic duct with consequent chylothorax may occur during operative procedures in the neck or thorax, may be caused by the penetrating agent, or may follow some type of trauma such as crushing injuries in which the chest is not penetrated but in which the duct is torn by fractured rib fragments or ruptured probably as a result of the compression together with an increased intraductal pressure which may be present following a heavy meal (254). It would seem that the majority of cases follow non-penetrating injuries. Thus in Macnab and Scarlett's (270) series of 33 collected cases, 27 (81.8 per cent) were due to crushing injuries and only 6 (18.1 per cent) followed penetrating chest wounds. In 1936 Strauss (412) reported a case following a bullet wound and was able to find only 7 other cases in the literature. More recently another case was reported by Matson and Stacy (279). Traumatic chylothorax occurs most frequently on the right side. Of 28 cases reviewed by Macnab and Scarlett (270) 15 were on the right side, 8 on the left, and 5 were bilateral. Clinically the three most striking features according to Lillie and Fox (259) are: "the latent period before the onset of the symptoms, the rapid reaccumulation of the fluid within the chest after aspiration, and a gradual progressive emaciation which frequently ends in death." The average duration of the latent period is about four days. The clinical manifestations develop suddenly and dramatically with all the symptoms and signs of profound shock. Examination of the chest reveals evidence of pleural effusion and on aspiration, which combined with

other appropriate measures usually relieves the manifestations of shock, the characteristic chylous fluid indicates the diagnosis. In this connection it is important to distinguish between true chylous fluid and pseudochylous fluid. There are a number of physical and chemical determining factors in their differentiation (448). The unusually large amounts of fluid and the rapidity with which it reaccumulates following aspiration are quite characteristic. Cases have been reported in which the amounts aspirated varied from 20 liters in ten days (349) to 52 liters in thirty-four days (259). The grave prognosis in traumatic chylothorax is shown by the fact that the mortality in the reported cases is about 50 per cent. In Mouchet's (298) collected series of 43 cases, the mortality was 41 per cent and this incidence in Macnab and Scarlett's (270) series was 53.3 per cent. Obviously the prognosis is better in injuries of the thoracic duct occurring at operation and limited to this structure. In the fatal cases death may be immediately due to suffocation and cardiac failure as a result of the massive pleural effusion or be delayed for several weeks with terminal features of inanition, emaciation, and asthenia. The management of traumatic chylothorax following injuries of the thoracic duct is more or less unsatisfactory as surgical repair of the defect is impracticable although ligation may be advantageously done in cervical injuries. Various forms of therapy, some of which are contradictory, have been suggested including the administration of large amounts of fluids by mouth, the restriction of oral fluids and their rectal administration (180), the administration of a fat-free diet (259) and a diet rich in fats, the use of blood transfusion and glucose-saline mixtures and the avoidance of glucose infusions (81), the production of positive intrathoracic pressure to favor compression and closure of the duct by thoracotomy, thoracoplasty or artificial pneumothorax which appears irrational, the use of gomenol and oil injections (279), the intravenous re-introduction of the aspirated chyle (19, 317, 399, 455) and the performance of phrenicotomy (310). It would seem that probably the best plan of management should consist of the use of supportive measures and emergency aspiration to relieve cardiorespiratory embarrassment. If the aspirated chyle is sterile its intravenous reintroduction appears rational.

Injuries to the diaphragm resulting in traumatic diaphragmatic hernia may follow blunt non-penetrating trauma causing a bursting tear of the diaphragm or may be due directly to the penetrating agent as in stab and gunshot wounds.

Diaphragmatic hernia may be etiologically classified into congenital, acquired, and traumatic (198, 199). In a comprehensive consideration of this subject in 1934 Hedblom (198) found that in a collected series of 1,003 cases reported since 1900, 34.9 per cent were of traumatic origin. Apparently the incidence of penetrating and non-penetrating trauma as a cause of diaphragmatic injury is about equal. In Hedblom's (198) series of 318 civil traumatic cases 52 per cent followed penetrating injuries and 48 per cent non-penetrating. Of the former 70.3 per cent were stab wounds, 21.3 per cent gunshot wounds, and the others were probably due to operative injury. In the non-penetrating group 36.6 per cent resulted from falls, 22.8 per cent from crushing injuries, 10 per cent to "jackknifing" injuries, and the remaining to violent strain. More recently the incidence of the non-penetrating type may be increased due to the great frequency of automobile and airplane accidents. In war wounds the penetrating type is probably more frequent. In this connection, however, Gordon-Taylor (168) recently stated that "in contrast to the last great European conflict non-penetrating injuries of the abdominothoracic zone do not play the same small and infrequent part in war surgery today." In Hedblom's (198, 199) series there were 127 cases due to war injuries, of which 44 were caused by bullets, 32 by shell fragments, and 2 by bayonets. As might be expected, on the basis of anatomical considerations the left side is much more frequently involved than the right. In a series of 291 collected cases approximately 95 per cent were on the left side (199), of which approximately one-half were laterally located and one quarter centrally situated. Bilateral involvement is occasionally reported (285). Characteristically the clinical manifestations of traumatic diaphragmatic hernia vary considerably and depend to a great extent upon the size, position, and contents of the hernia as well as other associated injuries. In the non-penetrating type the most common immediate symptoms are shock and pain and other manifestations previously considered in crushing injuries. Dyspnea, tachycardia, upper abdominal tenderness, and rigidity and pain referred to the neck and shoulder are characteristic manifestations. In the penetrating form in addition to shock and pain there may be pneumothorax, hemothorax and other manifestations of associated intrathoracic injury. Later in both types there may develop symptoms referable to the thorax, abdomen, or both, which depend upon the size, position, and contents of the hernia and their consequent interference with cardiorespiratory

and gastro-intestinal functions. It should be realized that not infrequently patients are symptomless for long periods, and manifestations may not become apparent until years later. Eliot (129) reported a case in which the patient received a bayonet wound in the left side during the World War. This apparently healed promptly with no complications, but about twelve years later he noticed a swelling in the scar and sharp pain in the chest immediately after lifting a heavy trunk. At operation it was found that this was due to the herniation of omentum through an opening in the diaphragm. Bayonet wounds of the diaphragm apparently occur very rarely as in a series of 50 cases occurring during the last World War Bryan (71) states he never observed this type of injury. The physical findings are usually limited to the chest and also may vary considerably especially with postural changes. These include a changing percussion note over the lower thorax, borborygmi, and partial dextrocardia. The diagnosis of traumatic diaphragmatic hernia is frequently difficult to establish especially at the time of injury. That such injuries are commonly overlooked is demonstrated by Hedblom's (197) finding that of 127 cases during the last World War "over 40 per cent had symptoms from one to fifteen years before the diagnosis was made." Similar observations have been made by others (307, 379). For this reason the condition should be suspected in all thoracic injuries and especially in penetrating wounds of the lower thorax. Later the diagnosis is based upon the history of an injury, the presence of clinical manifestations, and roentgenological demonstration of an abdominal viscus above the diaphragm. Strangulation, usually of the omentum or a part of the colon but occasionally of the small bowel or stomach, is an obviously serious complication (71).

In the management of diaphragmatic wounds shock and other manifestations of the injury may require immediate attention. However, as soon as it is permitted by the patient's condition, surgical repair of the hernia should be done (275). Technical considerations of the operation will not be reviewed here as they have been presented in numerous previous publications (71, 185-187, 196-199, 377, 409, 430-432, 456). Several approaches have been employed including thoracotomy, laparotomy, or a combination of both. The indications, contraindications, advantages and disadvantages of each method have been discussed previously (197-199). In traumatic diaphragmatic hernia, especially if associated with other thoracic injuries, it would seem that the thoracic approach is more desirable. However,

the approach should be determined by the indications in the individual case. Interruption of the phrenic nerve by novocaine injection or preferably by crushing facilitates the operation (9, 140, 185-188, 197, 199). In those cases in which operation is performed immediately after the injury careful exploration of the subdiaphragmatic region should be done to determine the possibility of damage to structures in this area. The prognosis in non-complicated cases is fairly good. Immediate fatalities are usually due to other more serious injuries although cases have been reported in which the diaphragm only was injured (88). Thus, in 12 cases due to gunshot and stab wounds recently reported by Steinke (406, 407) there were 8 deaths (66 per cent) all but 1 of which were due to hemorrhage. Hedblom (197-199) found that the operative mortality in the collected series of civilian cases was 17 per cent in the non-obstructed group and 81.6 per cent in the obstructed. In war injuries these respective figures were 26.3 per cent and 37.6 per cent. More recently Harrington (186) reported 210 cases of diaphragmatic hernia including 36 of traumatic origin with a total operative mortality of 4.3 per cent.

Because of their relative gravity thoracic-abdominal wounds deserve especial consideration. In the American Expeditionary Forces during the last World War these wounds comprised 4.6 per cent of all thoracic injuries admitted to the evacuation hospitals (247). According to Taylor (420) in the British Forces during this war these wounds constituted about 9 per cent of the thoracic wounds admitted to a casualty clearing station and about 12 per cent of the abdominal cases. Similarly in the Spanish Civil War these wounds comprised 11 per cent of all abdominal wounds (221). Penetrating injuries and especially war wounds are the more serious forms because not infrequently they are multiple. In a consideration of this subject Duval (14) states that if the wound of entry is in the chest the more serious lesions are likely to be thoracic whereas if the entry wound is abdominal the graver lesions are more apt to be in the abdomen. Obviously in multiple wounds any of the thoracic lesions previously considered may be encountered as well as involvement of the various intra-abdominal viscera. Diaphragmatic wounds are frequent especially in injuries of the lower thorax, and herniation of abdominal viscera, especially on the left side, occurs in about 10 per cent of these cases (247). Bryan (71) has presented an excellent review of this complication of thoracic-abdominal wounds occurring in the last World War. Lee

(247) states that a hollow abdominal organ is penetrated in approximately one-third of the cases and that "an uncomplicated liver injury is more common than one of the spleen." It should be realized also that thoracico-abdominal lesions with rupture of the liver or spleen may follow crushing injuries (98). Heyd (209) classifies thoracico-abdominal injuries into six types: "(1) The perforating wound through the costophrenic sinus with minimum degree of damage to diaphragm and which was characterized usually by slight, if any, visceral lesion. (2) Penetrating wound with orifice of entry high on the thorax, perforating the lung and penetrating the diaphragm with moderate or severe visceral injury. (3) A wound low down in the axillary line, usually in the seventh, eighth, or ninth intercostal space, with injury to the liver, spleen, and stomach, with gross hemorrhage into the abdomen, and rarely perforation of the colon or small intestine, and in which the entire picture was dominated by the abdominal injury. (4) A wound low down in the axillary space with considerable loss of lateral chest wall and diaphragm, resulting in herniation or prolapse of the omentum and abdominal viscera into the thoracic cavity or externally. (5) A wound in the lumbar region with injury to the kidney and associated with injury to diaphragm and abdominal viscera. (6) Tangential wounds of the chest and abdominal wall with a concussion haemothorax and suspected chest and abdominal injury, but which upon operation proved to be superficial and without injury to either thoracic or abdominal viscera."

In addition to shock, which is almost invariably present early, the clinical manifestations are variable and depend upon the extent and type of visceral involvement. Accordingly, there may occur hemothorax, pneumothorax, emphysema, or any of the manifestations previously considered in thoracic injury. Rarely bilithorax or cholothorax has been encountered (49, 135, 414). In addition to these manifestations abdominal pain, localized tenderness and rigidity especially in the upper part of the abdomen, vomiting, and evidence of intraperitoneal hemorrhage are frequently present. It should be realized that pseudoperitoneal reactions may occur in injuries of the lower thorax (271, 397) with resultant confusion in diagnosis. Maillet (271) has directed attention to this possibility which he refers to as "syndrome-phreno-diaphragmatique." Upper abdominal pain, tenderness, rigidity, and even manifestations of ileus may be present. However, the subsequent course of the condition reveals the injury to be primarily thoracic. In some instances

the manifestations are due to injury or irritation of the intercostal nerves (358) and the diaphragm. In this connection Gordon-Taylor (168) states that whereas "abdominal rigidity associated with an injury below the diaphragm is more likely to be bilateral," such rigidity accompanying thoracic wounds "is usually confined to one side." Moreover, in chest injury the abdominal rigidity "tends to be intermittent, some relaxation of the rectus abdominus occurring during inspiration." Roentgenological studies in the diagnosis of these injuries are obviously indispensable.

In the management of thoracico-abdominal injuries certain principles of therapy have been established and depend upon the type of injury. Obviously shock must be combated before other active therapeutic measures are instituted except in the presence of those thoracic injuries previously considered, such as tension or valvular pneumothorax and "sucking" wounds, which demand immediate attention. In cases of open pneumothorax obtained early, some advise immediate operation with débridement of the chest wall and radical enlargement of the diaphragmatic wound to permit exploration of the diaphragmatic area. In through-and-through wounds on the right side with probable liver penetration conservative therapy is probably indicated unless continuing hemorrhage becomes manifest. According to Gordon-Taylor (168) surgical intervention in injuries of the liver is indicated (1) in gross hemorrhage from this organ, (2) in the presence of an associated thoracic or "abdominal lesion demanding exploration, and (3) if a large missile is retained in an accessible part of the liver." In diaphragmatic injuries associated with kidney wounds it is considered preferable "to do the posterior surgery first" (209). In wounds on the left side with splenic injury, splenectomy is probably the procedure of choice especially if abdominal exploration seems warranted. Gordon-Taylor (168) states that "suture of the spleen may not be difficult when the organ is approached through the chest and diaphragm, but when explored by other routes cobbling of the organ is wasteful of time and may leave a sense of insecurity." He refers to a number of successful transdiaphragmatic splenectomies in abdomino-thoracic wounds on the left side during the last World War. In some of these cases this was associated with nephrectomy and repair of gastric wounds. In cases of small penetrating thoracic wounds with abdominal injury especially of the hollow viscera operative intervention directed at the abdomen is indicated and the thoracic lesion may be temporarily disregarded (411). Such in-

juries usually involve the stomach and splenic flexure of the colon. On the other hand if the wound involves the thorax, diaphragm, and abdomen and the thoracic injuries are sufficiently serious to warrant operation, surgical intervention should be directed toward the chest injury and the upper abdomen may be approached through the diaphragm. Occasionally it may be necessary to explore both the chest and abdomen through separate openings or through a vertical incision over the chest with section of the costal cartilages and prolongation of the incision into the abdomen (117).

The prognosis in these injuries is obviously grave. Heyd (209) stated that during the last World War "in the forward area" the mortality was usually 60 per cent, but not infrequently 75 per cent. According to Taylor (420) it is "largely determined by the nature of the abdominal injury." Thus, the cases associated with wounds of a hollow viscus had a higher mortality. In his series of 75 cases Taylor found that while the mortality incidence was 50 per cent in the cases accompanied by injury to a hollow viscus, in those with wounds of a solid viscus it was 30 per cent. The total operative mortality in a collected series of 207 cases occurring during the last World War was 33.3 per cent. According to Gordon-Taylor (168) the prognosis is worse in "wounds that traverse the diaphragm from below upwards" than in those "in which the missile has passed from thorax to abdomen."

Because of its particular significance, it is deemed desirable to consider briefly the problem of anesthesia in chest injuries. The importance of anesthesia in war wounds and military surgery has been recently emphasized by Metcalf (284) and Crane and Sankey (96). Anesthesia in elective thoracic surgery presents certain distinctive difficulties which have been generally realized (26-29, 139, 208, 211, 216, 269, 340, 366, 376, 462). However, in chest injuries the problem is further complicated by the presence of anoxia, shock, and other factors which may embarrass cardiorespiratory function such as rib fractures, massive atelectasis, tension or open pneumothorax, massive hemothorax, varying degrees of pneumonitis, and intrapulmonary hemorrhage. In a recent consideration of this subject Halton (181) has directed attention to the fact that "wound shock, through the direct action of nervous impulses and tissue metabolites on the respiratory enzyme, reduced cytochrome, interrupts the cycle of cell respiration and oxidation," and that "morphia and the anesthetic drugs acting on another respiratory enzyme, dehydrogenase, further tend

to retard the vital cycle and to produce oxygen starvation of the tissues." Obviously operative intervention should be avoided in the presence of shock except under the unusual circumstances previously considered. However, even in those cases of chest injuries in which the surgical procedure has been delayed and a sufficient period has elapsed for readjustment, there are present a number of factors which "render the margin between oxygen sufficiency and oxygen lack very narrow" (181).

Apparently there is some diversity of opinion regarding the most desirable method of anesthesia in these cases. Halton (181) is opposed to the closed circuit method because it is "mechanically and physiologically inadequate." He states that whereas the mediastinum and lung can be stabilized "if the gases are given under pressure, . . . the increased effort of expiring against this pressure has the same effect as if the patient were breathing ordinarily with one side of the chest open. Again, though the exhaled gas is washed clean of carbon dioxide the air which passes from lung to lung never reaches the absorbing medium so the vicious circle described above is never broken. Its effects are merely delayed and minimized for a short time. Moreover, if the other pleural cavity is opened by accident or intent, it is impossible with this form of anesthesia to keep the patient alive for more than a short time." Halton (181) considers intratracheal insufflation the method of choice in either immediate or delayed procedures and uses ether or chloroform because although nitrous oxide or cyclopropane may be "ideal in theory" they are "too expensive for general use." Moreover, he prefers not to employ premedication such as morphine or intravenous barbiturates in the majority of cases "because of their depressant effect on the respiratory centre which is already overburdened." On the other hand, Nosworthy (309) states that "in practically all these war cases" he has employed "controlled respiration, using the carbon dioxide absorption, technique," because in his experience it is the only method "which permits normal respiratory physiology to take place while the chest wall is wide open." In discussing his reasons for using this method of anesthesia he states further that it "completely prevents paradoxical respiration, mediastinal flap, and all disturbances from sucking wounds. Both pleural cavities can be opened simultaneously without harm. The patient's existing vital capacity is used to the full. In view of the adequate oxygenation and efficient removal of carbon dioxide, even very ill patients stand up to prolonged operations so well that one has come

to expect them to be no worse, and commonly better, at the conclusion of the operation. The surgeon's work inside the chest can be made less difficult, and at the end it is almost always possible, if one so desires, to leave the lung on the affected side fully expanded." He uses cyclopropane which he considers the anesthetic of choice. It "is non-toxic, of short action, and permits the use of a high concentration of oxygen." Moreover, he also employs premedication and for this purpose administers "morphine and scopolamine with or without an intravenous injection of pentothal sodium." Westell (458) also prefers intravenous induction and states that in his experience intravenous anesthesia "combined with endotracheal insufflation of oxygen under pressure, supplemented by nitrous oxide if necessary" has been found excellent. During the last World War there was also some diversity of opinion regarding the preferable method of anesthesia. In the American Forces "positive pressure anesthesia, or, better, analgesia" was considered "the most important single factor in successful thoracotomy under war conditions" (469). Nitrous-oxide-oxygen was employed with the Gwathmey apparatus and morphine was used in premedication. On the other hand, the French and English Surgeons preferred open anesthesia or local analgesia (5, 115, 160, 171, 192, 262, 264, 357, 440). As previously emphasized in the consideration of anesthesia in intrathoracic surgery "the most important desiderata are complete control of intrapulmonic pressure, adequate facilities for aspiration of secretions in the respiratory passages during the operation, the maintenance of quiet respirations and high oxygenation, the avoidance of distressing cough reflex, and the rapid return to consciousness following completion of the operation" (314). Although there is some diversity of opinion concerning the most desirable method of anesthesia in these cases, there is undoubtedly general agreement that a highly trained anesthesiologist, skilled in the management of cases requiring thoracic surgery, is extremely important. As emphasized by Thomas (423) "only those of us who constantly practice thoracic surgery . . . fully appreciate how much a successful outcome depends on the skillful anaesthetist in a difficult case."

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